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# GEOLOGICAL SOCIETY

OF

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VOL. 6

JOSEPH STANLEY-BROWN, *Editor*

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*COUNCIL FOR 1895*

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(27 plates; 40 figures.)

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### Regular Publications

The Society issues a single serial publication entitled Bulletin of the Geological Society of America. This serial is made up of *proceedings* and *memoirs*, the former embracing the records of meetings, with abstracts and short papers, list of Fellows, etcetera, and the latter embracing the larger papers accepted for publication The matter is issued as soon as possible after acceptance, in covered brochures, which are at once distributed to Fellows and exchanges. The brochures are arranged for binding in annual volumes, which are elaborately indexed.

The Bulletin is sold to Fellows and the public either in full volumes or in separate brochures. The volume prices are, to Fellows, a variable amount, depending on the cost of publication; and to libraries and to the public, the fixed amounts given below. The brochure prices for volumes 1 and 2 are given on pages ix–xi of volume 2; the prices for the brochures of volume 3 are given on pages viii–ix of that volume.

Volume 1, covering the work of the Society from the organization, in 1888, to the end of 1889, comprises 593 + xii pages, 13 plates and 51 cuts. Price to Fellows, $4.50; to libraries, $5.00; to the public, $10.00.

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## Irregular Publications

In the interest of exact bibliography, the Society takes cognizance of all publications issued either wholly or in part under its auspices. Each author of a memoir receives 30 copies without cost, and is authorized to order any additional number at a slight advance on cost of paper and presswork; and these separate brochures are identical with those of the editions issued and distributed by the Society. Contributors to the Proceedings are also authorized to order any number of separate copies of their papers at a slight advance on cost of paper and presswork; but such separates are bibliographically distinct from the brochures issued by the Society.

The following separates of parts of volume 6 have been issued:

*Editions uniform with the Brochures of the Bulletin.*

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* Bearing the imprint [" From Bull. Geol. Soc. Am., vol. 6, 1894."]
† Fractional pages are sometimes included.

## CORRECTIONS AND INSERTIONS

All contributors to volume 6 have been invited to send in corrections and insertions to be made in their compositions, and the volume has been scanned with some care by the Editor. The following are such corrections and insertions as are deemed worthy of attention:

Page 74, line 13 from top; *for* "and that" *read* "but that farther north"
" 175, " 20 " " ; *strike out* "*Raphistioma minnesotensis*, Owen"
" 268, footnote; *for* "schiefer Gesteine" *read* "Schiefergesteine"
" 270, line 27 from top; *for* "transition" *read* "gradation"
" 274, " 6 " bottom; *for* "transition" *read* "gradation"
" 276, figure 5; *for* "northeast" *read* "southeast"
" 276, " 6; *for* "Gabbro Inclusion" *read* "Gneiss Inclusion"
" 285, plate xii; in section *Y–Y*, fault *K–K* should throw to the north.
" 328, line 14 from top; *for* "323" *read* "324"

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 6, PP. 1-28 NOVEMBER 23, 1894

# PROCEEDINGS OF THE SIXTH SUMMER MEETING, HELD AT BROOKLYN, NEW YORK, AUGUST 14 AND 15, 1894

HERMAN LE ROY FAIRCHILD, *Secretary*

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## SESSION OF TUESDAY, AUGUST 14

The Society convened in room 11, second floor of the Packer Institute. In the absence of the President, Vice-President N. S. Shaler presided during the several sessions of the meeting. After the call to order, at 10 o'clock a m, the acting President spoke a few words of salutation, and announced the death of two Fellows, Professor George H. Williams, of Baltimore, and Mr Amos Bowman, of Anacortes, Washington.

*ELECTION OF FELLOWS*

The Secretary announced the result of the balloting for Fellows, as canvassed by the Council, as follows:

*Fellows Elected*

Miss Florence Bascom, A. M., B. S., Ph. D., Columbus, Ohio. Instructor in Geology, Petrography and Mineralogy in the Ohio State University.

Richard Charles Hills, Denver, Colorado. Mining Engineer.

Elfric Drew Ingall, Geological Survey Department, Ottawa, Canada. Mining Engineer. In charge of Division of Mineral Statistics and Mines.

Robert Tracy Jackson, S. B., S. D., 33 Gloucester street, Boston. Instructor in Paleontology, Harvard University.

David F. Lincoln, M. D., Geneva, New York.

Charles Joseph Norwood, Frankfort, Kentucky. State Geologist and State Mine Inspector of Kentucky.

Charles Palache, B. S., Ph. D., Berkeley, California. Fellow in Geology in University of California.

Louis Valentine Pirsson, Ph. B., New Haven, Connecticut. Instructor in Geology and Petrography in Sheffield Scientific School, Yale University.

Henry Lloyd Smyth, A. B., Cambridge, Massachusetts. Instructor in Mining Geology and Geological Surveying in Harvard University.

Lewis Gardner Westgate, 1303 Chicago avenue, Evanston, Illinois.

William Smith Yeates, A. B., A. M., Atlanta, Georgia. State Geologist of Georgia.

A communication from the Royal Society of London was read by the President, which referred to coöperation and aid in the matter of publishing the "Catalogue of Periodical Scientific Literature." It was voted, after some discussion and amendments, to appoint a committee of three, the acting President as chairman, to consider the matter of the communication and report at the winter meeting. The committee as named consists of N. S. Shaler, H. S. Williams and W J McGee.

The Secretary announced that the Council desired to apply the rule regarding the presentation of papers whose authors were absent that was applied at the preceding winter meeting. The rule is as follows:

"The Council rules that papers whose authors are not present when the title is called shall go to the end of the program unless the Society by special vote in each case decides otherwise."

The Secretary stated that the titles in the printed program had been arranged according to the classification given in the last report of the Council (volume 5, page 613), and that it was proposed to adhere to this order in the programs of future meetings; also to place at the head of the list the titles in that department of geology which had been at the foot of the list the preceding meeting, thus bringing all the several groups

in rotation, during successive meetings, to the head of the program. The adoption of this rule will enable the Fellows to determine beforehand the relative position of their papers in the program. In accordance with this plan, the papers on petrography and mineralogy at this meeting headed the list.

The reading of papers was declared in order, and the first title announced was as follows:

### *THE NICKEL MINE AT LANCASTER GAP, PENNSYLVANIA, AND THE PYRRHOTITE DEPOSIT AT ANTHONY'S NOSE, ON THE HUDSON*

BY J. F. KEMP

[*Abstract*]

The paper described, with maps, sections, lantern views and specimens, these two deposits of nickeliferous pyrrhotite. The former is on the contact between a great intruded lens of some original, basic, intrusive rock—now altered to a mass of coarsely crystalline, green hornblende (*i. e.*, it is an amphibolite)—and its walls of mica-schist and pegmatite. The latter is a lens or pod of the type familiar in the iron mines of the highlands of New York and New Jersey, and is in acidic gneiss of the oomposition cf granite. The question of origin was discussed with especial reference to magmatic separation, and with comparisons with nickel ores elsewhere in America and in Norway.

Remarks were made by Alfred C. Lane, W. N. Rice and Frank D. Adams.

This paper will be printed in full in the Transactions of the American Institute of Mining Engineers, Bridgeport meeting, October, 1894.

The second paper was—

### *A CONNECTION BETWEEN THE CHEMICAL AND OPTICAL PROPERTIES OF AMPHIBOLES*

BY ALFRED C. LANE

[*Abstract*]

The following law seems to apply to all the hornblendes, so far as the data go, with one exception:

The amount of $Na_2O$ contained $=90 / 17$ (0.012 — (the birefraction of the ortho-pinacoidal section) ), said birefraction being considered + or — according as the character of the extinction is + or —.

The data are limited; the constants only approximate. It is therefore very desirable that those making hornblende analyses should also measure this birefraction. It also remains to be seen how far this law holds, for it cannot be expected to be true throughout the group.

In the absence of the author, the third paper was held in its place by vote, and it was read by J. F. Kemp.

## *ON A BASIC ROCK DERIVED FROM GRANITE*

BY C. H. SMYTH, JR.

[*Abstract*]

Intimately associated with the hematite of the Old Sterling mine, Jefferson county, New York, is a dark, rather massive rock, which was described by E. Emmons as serpentine and has always been referred to as such. Some portions of the rock closely resemble serpentines, but most of it contains numerous irregular grains of quartz. The field relations are those of intrusive rock, but the abundant quartz indicates that it could hardly be of the basic character usually found in rocks which alter to serpentine. The true nature of the original rock is shown by a few limited areas which have suffered comparatively little change. These cores of unchanged rock are but a few yards in extent and consist of a reddish coarse-grained granite composed chiefly of quartz and feldspar. This granite, evidently very acid, shades gradually into the surrounding dark colored rock of serpentinous aspect. Under the microscope this change is seen to result from the gradual replacement of the feldspar, and to a less degree of quartz by an aggregate of minute green or yellow scales. Every stage of the process is shown from a slight alteration of feldspar to a complete replacement of all of the constituents of the granite by the green aggregate. As to the mineralogic affinities of the aggregate it seems more closely related to the chlorites than any other minerals, and is quite different from serpentine. Chemical analysis of a completely altered specimen shows about 30 per cent of $SiO_2$, 12 per cent of $H_2O$, 11 per cent of MgO, and 27 per cent of FeO. These figures show a great amount of change from the original acid granite and point to chemical rather than mechanical agents as the chief factor in the process. The rock is considerably crushed, but it is probable that this acted chiefly in giving access to the solutions causing the alteration, as dynamo-metamorphism alone does not usually change the bulk composition of a rock so greatly. From the large amount of iron in the rock, together with the fact that similar rocks occur at all the iron mines, but nowhere else in the vicinity, it seems reasonable to infer that there is a causal connection between the iron ore and the altered granite. Several facts indicate that the ore is a replacement of limestone, probably through the action of solutions derived from oxidizing pyrites near at hand. Such solutions, together with those resulting from the dissolving of the limestone, would afford just the sort of agent required to effect the profound change shown in the granite.

Remarks were made upon the paper by Jed Hotchkiss.

The next paper was—

## *A STUDY OF THE CHERTS OF MISSOURI*

BY EDMUND O. HOVEY

H. S. Williams and N. S. Shaler made remarks upon the matter of the paper, which is printed in the American Journal of Science for November, 1894, vol. xlviii, pp. 401–409.

Passing several papers whose authors were absent, the next paper presented was—

### *DISLOCATIONS IN CERTAIN PORTIONS OF THE ATLANTIC COASTAL PLAIN STRATA AND THEIR PROBABLE CAUSES**

BY ARTHUR HOLLICK

[*Abstract*]

Extending from Nantucket, Marthas Vineyard, through Block island, Gardiners island, Long island, Staten island and northern New Jersey, there is a clearly marked line or area of disturbance which presents many features entirely different from those with which we are familiar elsewhere. A portion has been considered by Professor N. S. Shaler to represent mountain-making effects, while the writer is satisfied that ice action has produced similar phenomena.

From a careful study of the region as a whole, we are now in a position to state, as beyond question, that this line of disturbance is coincident with the line of the terminal moraine from Nantucket to northern New Jersey; that the phenomena of folding and crumpling in the Cretaceous and post-Cretaceous strata are only to be found where the moraine has advanced over some portion of the former coastal plain, and that these phenomena cease abruptly where the moraine bends away from or finally leaves the plain.

The writer is of the opinion that one series of cause of effect has been instrumental throughout, and the question at issue seems to be which of the two theories just referred to is supported by the greater weight of evidence.

Beginning with Marthas Vineyard, we may consider the general structure there as typical of the region elsewhere. The island consists essentially of a series of hills in the north, composed of a core of Cretaceous and post-Cretaceous strata, tilted and folded, flanked on the north and capped on the top by bowlder till which gradually merges into water-assorted material on the southern flanks and extends over the plains beyond. The Gay Head escarpment is the most extensive section across the line of disturbance which is anywhere exposed to view.

Proceeding westward, we find a similar structure to exist on Long island, although the exposures are far more limited, but it is only necessary to imagine Long island separated into parts by convenient north and south erosion channel, in order to reproduce Gay Head indefinitely.

On Staten island the facts are even of greater significance and interest. The moraine crosses a portion of the coastal plain near the Narrows, thence bends northward, rests on the Archean axis, and again enters upon the plain a few miles further west. Throughout both portions of the moraine where it rests on the coastal plain evidences of dislocation and distortion are to be seen. Between these portions there is not the slightest indication of any disturbance and the topography of the plain is level and uniform. This little area seems to have been specially preserved as an object-lesson in this connection.

In northern New Jersey the evidences of disturbance are not so manifest, which may perhaps be accounted for on the supposition that the ice, having advanced over this portion of the plain from a comparatively level area, did not plow down

*The paper was illustrated by charts and maps of the region under discussion and by sketches of many of the localities mentioned.

to the depth which it did in the case of Long Island sound, where the advance was over a hard rock escarpment.

As to the dip and strike of the disturbed strata they are found to be too erratic to be of much stratigraphic value, but there is a prevailing strike coinciding with the trend of the moraine, and the strata are either bent into overthrust folds or tilted, with the dip toward the north. North and south anticlines are also met with. At the sides of the harbors on the north shore of Long island the dip is often east or west, apparently due to lateral squeeze or thrust.

There seems to be but little question as to the competency of ice to produce the phenomena in question, and in this connection the recent experiments by Mr Bailey Willis * are especially apropos.

As favoring the theory of ice action we therefore have the general structure of the morainal region of the coastal plain; the uniform coincidence of distorted coastal plain strata with the line of the moraine; the absence of any distortions where the moraine does not reach the plain; the much more pronounced distortions where the moraine indicates an extensive advance of the ice over the plain, and the prevailing directions of dip and strike.

The only element which enters into the theory of mountain-making forces as the probable agency which is not also an argument for the ice theory is that of geologic age. The topography of the Marthas Vineyard hills is considered by Professor Shaler to be preglacial. If this be the fact, then the phenomena of dislocation in Marthas Vineyard must be considered as isolated from the remainder of the region and as due to a different cause. The writer failed to see the evidence of it, and it is certainly not the case elsewhere. Thus we find beds of "yellow gravel," the equivalent of the Lafayette formation, included as part of the distorted strata, showing that the disturbance took place subsequent to the period when these gravels were laid down. All authorities are now practically agreed that this formation is at least as recent as the Pliocene, and, considering this fact alone, we should have a very brief period of time in which to develop any preglacial topography. It would imply a very great stress, suddenly and violently discharged—almost in the nature of an eruption in fact—and not a gradual mountain-making process. So far as my experience goes, the facts do not warrant us in assuming that such conditions have prevailed.

Finally, any such development of force would result in the disturbance of strata far below the surface, as well as above, and this we do not find to be the case. As a single example, we may take the exposure at Cold Spring, Long island, where the superficial strata are beautifully folded and crumpled, while the lower ones below the area of ice action are undisturbed. The significant fact should also be remembered that the line of disturbance extends in a generally east and west directions instead of north and south—the direction in which experience and observation would lead us to expect that mountain-making forces in this region would be manifested.

On the other hand, the theory of ice action in connection with the continental glacier of the Ice age seems to be both a rational and an adequate one. The fact, are in harmony with it; it enables us to consider the entire area of disturbance as a comprehensive whole, with one series of cause and effect throughout, and not as

* "The Mechanics of Appalachian Structure," extract from the Thirteenth Ann. Rept. of the U. S. Geol. Survey, 1891–'92, pp. 217–281.

a number of isolated districts in which identical phenomena are to be accounted for on different hypotheses. It is also a theory which nothing in our previous observation or experience would cause us to doubt, and is one which has been applied to similar phenomena in Europe, especially in the islands of Moën and Rugen, in Denmark.

In discussing Mr Hollick's paper Acting President Shaler said:

My objections to Mr Hollick's paper may be summed up as follows: On the western end of the island of Marthas Vineyard, a region which Mr Hollick has not personally examined, series of Cretaceous and Tertiary rocks, having an aggregate thickness of several hundred feet, are folded into extended anticlinals and synclinals, the average dips of which exceed 40° of declivity. The width of this area of folded rocks is not less than five miles, extending entirely across the island. The average amplitude of the folds probably exceeds one thousand feet. The amount of the disturbance is as great on the southern side of the island, the region furthest removed from the main ice front, as it is on the northern side of the field. Moreover, the axes of the folds are not at right angles to the path of the glacial movement, but in a general way parallel to that course.

On this field of profoundly dislocated rocks there remains in an almost unaltered state the complicated erosion topography which existed when the region was invaded by the ice of the last glacial period. Considerable areas are destitute of erratic material. Scarcely any of the valleys have been so far obstructed by the drift that their forms are not readily distinguishable. Moreover, on the northern or shock side of the island there are many minor disturbances of the strata which may be reasonably attributed to the thrusting of the ice-sheet, but these dislocations greatly differ from the broad folds which characterize the other parts of the district. They seem to me to be imposed upon the preglacial topography.

For the reasons I have indicated, as well as for others which cannot be briefly stated, while granting that the horizontal thrusting of an ice-sheet may disrupt strata, I do not believe that the foldings of the Marthas Vineyard section are due to this cause.

Mr Hollick replied:

Professor Shaler is in error in regard to my not having personally visited and examined the western end of the island. The question seems to resolve itself into merely a difference of opinion as to the preglacial age of the topography.

It was voted to adjourn the further discussion until after the noon recess.

Upon reassembling at 2.15 o'clock p m J. W. Spencer spoke upon Mr Hollick's paper.

The first paper read was entitled—

### *RECONSTRUCTION OF THE ANTILLEAN CONTINENT*

BY J. W. SPENCER

Remarks upon this paper were made by W. B. Scott as to the Antillean faunas and their bearing upon the former land connection; by J.

J. Stevenson upon the latter point, and by W J McGee. The paper is printed in later pages of this volume.

The next paper was—

*EVIDENCES AS TO THE CHANGE OF SEA LEVEL*

BY N. S. SHALER

Remarks were made by J. W. Spencer, Joseph Le Conte, A. C. Lane and the acting President. The paper is printed in full in this volume.

The following paper was read:

*EXTENSION OF UNIFORMITARIANISM TO DEFORMATION*

BY W J MCGEE

The paper was discussed by N. S. Shaler, Joseph Le Conte, R. P. Whitfield, F. D. Adams and J. W. Spencer. The paper is printed in full in this volume.

Passing over several papers whose authors were absent, the next paper was—

*DRUMLINS IN THE VICINITY OF GENEVA, NEW YORK*

BY D. F. LINCOLN

Remarks upon the paper were made by George H. Barton.

The following paper was presented:

*GLACIAL ORIGIN OF CHANNELS ON DRUMLINS**

BY GEORGE H. BARTON

*Contents*



## Progress of the Study of Drumlins in Massachusetts

In connection with the work of the United States Geological Survey and under the direction of Professor N. S. Shaler nearly eighteen hundred drumlins have been mapped and studied in Massachusetts. The time allowed in which to cover so large

*Published by permission of the Director of the United States Geological Survey.

an area as the whole state has permitted only a general reconnaissance, rather than a detailed survey, and much more time is required to produce a well finished result.

### Symmetry of Drumlins a Protection against Erosion

The typical drumlin or lenticular hill of Hitchcock, with its smooth, flowing outlines, long, gentle slopes on the ends, and somewhat steeper slopes on the sides, and with no break in its curves, is the most symmetrical and graceful hill that nature produces. This very perfection of symmetry in form has enabled it to withstand the attacks of the rains and snows by causing the water to flow off with an even distribution, and thus preventing it from collecting in sufficient quantities to produce an incipient crease, which in time might be enlarged to a small gully and stream channel. The small amount of erosion that has taken place has been so evenly distributed over the whole surface that it is now practically impossible to even make an approximate estimate of its amount.

### Erosion of Drumlins

#### *CHARACTERISTICS OF POSTGLACIAL EROSION*

But the single typical drumlin is not the only form. There are groups of two, three or more, each member of which is nearly or quite perfect in itself and only touching its neighbor at its lowest periphery. In such cases the valley between has its bottom nearly or quite on a level with that of the surrounding country. In other cases the members of a group may be so closely joined together as to rise from the same base and have a quarter or a third of their mass in common, and then the bottom of the valley between is at an elevation far above the surrounding country level—an elevation one-third, one-half or two-thirds that of the summits on each side, but in all these cases the valley is one of construction, and its origin is in common with that of the drumlins themselves. Rain-water flowing down the adjacent slopes accumulates in these valleys in little streams, which erode small channels from either end of the valley to the base of the group. These features of postglacial erosion are common.

#### *CHARACTERISTICS OF GLACIAL EROSION*

Of a very distinct type, however, are the channels of erosion which form the subject of this paper and which are glacial instead of postglacial in their origin.

The longer axes of the drumlins are closely parallel in direction with the glacial grooves upon the rock surfaces in their own neighborhood, as in the central part of the state they are both nearly north and south, while in the neighborhood of Boston they are about southeast. The eskers, which are now generally believed to be formed by the accumulation of material in the bed of streams flowing on, in or under the ice-sheet, also agree fairly in direction with the above. This latter fact tends to show that the drainage of the glacial sheet was practically in the direction of its motion. So likewise these glacial stream channels with very few exceptions obey the same law and run southward. They cut the typical, symmetrical drumlin at all altitudes from the base to the exact summit ridge, and while winding as is usual with the course of a stream their general direction is parallel to the axis, though often they break through their lower bank and seek the shortest way down the steeper side to the bottom of the hill. Often they occur, passing

along the very summit axis, beginning sometimes far below the summit on the north end, cutting through the highest part on its way and continuing down the south slope to the base of the hill, its bed having a continuous southward slope from its first starting point. In a few cases, as at the hill south of Whittier's birthplace, in Haverhill, the channel passes along one side of the hill for some distance, then suddenly cuts transversely across its axis, and then passes southward along the opposite side. Some of the complex drumlins have a ridge-like form extending east and west or nearly so—sometimes divided on the summit by very shallow incipient valleys into separate summits—sometimes presenting no trace of such divisions. The erosion channels found on them may commence south of the east and west axis and slope down the south side, or they may begin on the north side one-half or more of the way up, cut through the axis and down the south side with a continuous south slope of the bed from its first appearance. The southward slope of the bed of the channel throughout its entire length is a marked characteristic, as it is very exceptional to find the northern portion of the bed sloping northward, though such cases do occur, as at Brown hill, east of Ayer Junction, and at North Leominster.

The same rule holds with the smaller channels, which, with rare exceptions, are found entirely upon the south slopes or on the southeast or southwest sides.

As an example for more detailed consideration, I have selected a drumlin having nearly the perfect typical form, which has a channel of moderate size nearly coincident with its longer axis for almost its entire length. This hill is situated in that part of the town of Stow known as Rockbottom, a region where drumlins are fairly numerous, there being from twenty-five to thirty within a radius of five miles. The Assabet river flows through this group, winding in curves of a mile or more in radius, but nowhere cutting into any portion of them nor having ever exerted an erosive power upon them. Directly north of the hill selected for detailed study and just across the river are two hills of the same elevation it has. One of them is a typical drumlin; the other an irregular mass of till. Within a third of a mile to the northeast and east, there are two more of similar character.

Southward about a quarter of a mile is a broad, flat mass of till, over which passes an esker, of which more will be said. Immediately to the west or slightly southwest is a nearly typical drumlin so closely connected with the one under discussion that the valley between the two is elevated one-half the height of the hills above the general level of the country.

The altitude of the bottom lands along the course of the river is 200 feet above sea-level, and above them the hill given on the map as Orchard hill, but known locally as Gleason's hill, rises about 100 feet, making its altitude above the sea 300 feet. It has a length of about half a mile and a width about one-half as great. As seen at a little distance from the east, it presents the smooth, graceful outlines of the ordinary type, except that it has a long, gentle slope to the south and a much steeper one to the north.

Ascending the type drumlin from the east to the line of the axial summit, a deep channel is found, which, from its winding, tortuous form, conveys the impression that it is a deserted water-course. Beginning at the north end of the hill, at an elevationn of about three-fourths its height, or 75 feet, it passes directly along the axis down the south slope, a distance of 2,000 or more feet, to the base. The bed has a southward slope throughout its entire course, except for a few feet at the north end, where the slope is northward. The greatest depth of the channel, 27

feet, is at the point where it cuts the highest portion of the hill, and south of that the slope of the bed is gentle—a little less than that of the hill itself—until it reaches the base.

A few rods south of the deepest point the depth is 26 feet, while at the same distance north it is but $17\frac{1}{2}$ feet. In each case these depths are taken from a line connecting the crests on each side, that on the west being always slightly lower—two or three feet—than that on the east.

At one point the bed is $3\frac{2}{3}$ feet higher than at a point some hundred feet farther up stream, but this is a common feature in the beds of streams with considerable slope. The greater depth at the latter point coincides with a bend of the stream that would produce greater velocity and a deeper erosion.

The bed is nearly free from bowlders, as is also the surface of the hill. This absence can be accounted for by the numerous stone walls in the construction of which all superficial stones have been used. A section of the interior of the hill has been exposed on the east side by sinking a well 12 feet in diameter and 50 feet in depth. The material excavated was a compact blue till, containing only a smal number of stones, not exceeding one or two feet in diameter, most of which were well glaciated. The small number here present would also indicate that but few would be left by erosion in the bed of the stream.

The outline of the hill, exclusive of the channel, indicates that it had been formed as a symmetrical, well shaped drumlin, and that in this completely formed hill erosion has taken place by some means directly along its axis.

## Origin of the Channels

Now, by what means and at what time was the action of a stream of water inaugurated at this elevation above the general level? It is necessary to suppose that at the time the stream came in contact with the north end of the hill it must have been flowing at an altitude as high or higher than that point. As this end of the hill is symmetrical below the channel and shows but slight, irregular indications of erosion, there must have been some material occupying this region to form a bed for the stream whose disappearance has left no visible trace. The only conceivable material that could so disappear is ice. Hence, at the time the channel was eroded, the ice-sheet must have lain to the northward, with a thickness exceeding the height of the hill and so impacted upon its northern slope that no current could pass downward in that direction. The stream, flowing over an ice-bed, came directly in contact with the summit of the hill, and thence onward eroded its channel in till to the base of the hill, where it lost its cutting power, and deposition ensued. Before reaching the hill the stream may have been superglacial or englacial. It could not have been subglacial; but from this point it may have been subglacial, as the ice-sheet may not have then entirely disappeared to the southward, or it may have entirely disappeared in that direction and the stream have thence been open to the sky.

Just at the bottom of the hill, in the broad mouth of the channel, is an esker-like ridge of a few rods in length, while the valley between this and the hill to the south is filled with kame material, some of which may have come from this source

Over the irregular mass of till to the south and in line with this channel winds an esker as a broad, flat ridge; but on the south slope the esker is replaced by a

narrow, sharp channel. In the valley south of this there is no indication of an esker; but, passing over the next elevation of till, a large mass divided into three summits, there are indications of erosion in the main valley, and then on the south slope there is a cirque-like hollow, which appears to have been excavated by a fall of water, as in a *moulin*. From the mouth of this runs an esker, having a height varying from 4 or 5 to 30 feet, which continues for a half mile, except where cut by a brook. With a few breaks, a line of eskers can be traced in this same linear direction as far as Hopkinton, a distance of ten or more miles. This shows a general line of glacial drainage to have existed in this direction. Directly north of Gleason's hill no eskers have as yet been found, though prominent ones exist both to the northwest and northeast.

At North Leominster, directly east of the station, is a large mass of till, which forms a common base, upon which rest some ten or eleven summits of various degrees of perfection. The largest channel yet seen is eroded out of the west end of this mass. The depth of this channel has not yet been measured, but it is probably between 80 and 100 feet. The width is correspondingly great, as the sides have not a very steep inclination. Here the amount of the material eroded is very large, yet so far no evidence has been found of its deposition elsewhere. The mouth of the channel opens directly toward the Nashua river, which is but a short distance away. It is probable that the detritus was carried into the floods which then filled the valley and by them was swept away, to be deposited farther down stream. This channel rises in a depression at the summit of the till mass and flows southward with a winding and gradually broadening course. The inclination of the bed is greater than that at Rockbottom. From the north side of the same depression from which this has its origin another passed down the north side, but this is more valley-like in appearance and has much less the characteristics of an erosional form. In this case no eskers seem to be connected with the channels.

Northwest of Worcester are three drumlins, not in direct line, each of which is cut by a channel and between each two of which are portions of eskers so arranged that the channels and eskers together form a nearly continuous serpentine line. The evidence seems to imply some kind of a connection in the origin of the esker and these channels. May not the same stream that produced the esker in one place have cut the channel in another? If a stream, either superglacial or englacial, were flowing on an ice-bed, material would accumulate in portions of its bed which subsequently formed the esker, but finding a mass of till, a more resistant material, in its course the action becomes then one of erosion instead of deposition, a channel is cut, and later, as the ice disappears, the esker is left in relief north and south of the channel, which is a representative of the same force.

About 300 channels of various sizes have been noted, but only in a few cases has time allowed for more than a hasty glance at each. As stated above, only a very small per cent of this number slope to the north; it is necessary to suppose in all these cases, as in the one at Rockbottom, that the ice-sheet lay pressed against the north side or end. What may have been the condition to the south is difficult to determine. It may have been that there the ice had entirely melted and that the front of the sheet was at the north of the hill, or it may be that melting had taken place directly over the southern slope of the hill, and that here the stream simply passed below the ice surface to become subglacial. Possibly further observations may clear up this point.

In conclusion, I wish to state that Professor Shaler called my attention during the early part of my work to a channel on Forbes hill, in Milton, which he had previously observed and to which he had ascribed a somewhat similar origin.

Following the reading of Mr Barton's paper the Society adjourned. No evening session was held.

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## Session of Wednesday, August 15

The Society was called to order at 9.15 o'clock a m.

Matters of business were deferred to a later hour of the session and the reading of scientific papers was resumed. The first paper was—

### *TRIAS AND JURA OF SHASTA COUNTY, CALIFORNIA*

BY JAMES PERRIN SMITH

Remarks were made by H. S. Williams.

The next two papers were not on the printed program, being offered late, but were presented by their authors:

### *GEOLOGICAL AGE OF THE MANGANESE DEPOSITS OF THE BATESVILLE REGION, ARKANSAS*

BY H. S. WILLIAMS

The paper was discussed by J. F. Kemp, Jed Hotchkiss and J. P. Smith.

### *REPORT ON THE PROGRESS IN GEOLOGY DURING THE PERIOD BETWEEN THE CENTENNIAL AND COLUMBIAN EXPOSITIONS*

BY JED HOTCHKISS

The matters of business were taken up.

The special committee appointed at the Madison meeting to consider and act upon the matter of making the Pacific Forest Reserve a national park presented the following report:

### *REPORT OF THE MOUNT RAINIER PACIFIC FOREST RESERVE COMMITTEE*

*To the Geological Society of America:*

At the Fifth Summer Meeting of the Society, held at Madison, Wisconsin, in August, 1893, a committee was appointed to take into consid-

eration the matter of making the Mount Rainier Pacific Forest Reserve a national reserve, and the committee was given power to memorialize Congress or take such other measures as they deemed advisable. The committee as originally elected consisted of David T. Day, S. F. Emmons and Bailey Willis. Dr Day requested to be excused from service on the committee on account of his want of familiarity with the region in question. The duties have consequently devolved upon the other two members, who beg to submit the following report:

Committees for the above purpose had also been appointed by the American Association for the Advancement of Science, the National Geographic Society of Washington, the Sierra Club of San Francisco and the Appalachian Club of Boston. Those members of either committee who happened to be in the city of Washington during the winter of 1893–'94 constituted a general committee, which held meetings from time to time, in conjunction with the representatives in Congress of the state of Washington, to consider and discuss the best methods of accomplishing the object desired.

Congress has of late shown some reluctance to create new national parks on account of the expense involved and because of the opposition of those who might desire to take up the lands thus reserved. In preparing the bill and accompanying memorial it was therefore necessary to use circumspection in order to avoid any possible opposition. The labor of preparing these papers has largely fallen on the members of your committee, who happened to be the members of the general committee most familiar with the geography of the region around mount Rainier.

A copy of the bill and memorial* which were submitted to the action of Congress by Senator W. C. Squire is enclosed herewith. From the map accompanying the latter, which was prepared by Mr Willis from the latest available data, it will be observed that the area of the proposed national park does not include the eastern half and extreme northern and southern edges of the forest reservation. Some of the citizens of the state of Washington consider these portions of possible value for mining or railroad purposes, and it was feared their opposition might jeopardize the success of the measure. The area given does, however, include all the glaciers and the most important scenic features in the vicinity of mount Rainier.

The bill which was introduced on July 26 was referred to the Senate Committee on Public Lands, and will probably not be acted upon until

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*Senate Mis. Doc. No 247, 53d Congress, 2d session. See also the speech of Senator W. C. Squire, of the state of Washington, in laying the memorial before the Senate, July 26, 1894.

the winter session of Congress. Senator Squire and the Honorable W. H. Doolittle, member of Congress from Washington, have shown great personal interest in the measure and will do their utmost to secure its passage. Your committee would suggest to any members of the Society who may be personally acquainted with members of either house of Congress to urge upon them the importance of reserving this unique and beautiful region for the public use.

Very respectfully submitted.

S. F. Emmons,
Bailey Willis,
*Committee.*

The documents referred to in the report were noticed by the acting President. The map referred to had been copied upon the blackboard. Remarks were made by W J McGee in response to questions.

It was voted to accept the report, with the thanks of the Society, and to continue the committee.

### *PROPOSED AMENDMENTS TO THE CONSTITUTION*

The Secretary announced that the Council would again submit to the Society the following proposed changes in the constitution:

To amend article iii, section 1, by omitting the closing words of the section, "and resident in North America," so that the section shall read: "1. Fellows shall be persons who are engaged in geological work or in teaching geology."

To amend article iv, section 8, by inserting after the word "Editor" the words "and Treasurer," so that the paragraph shall read: "The Secretary, Editor and Treasurer shall be eligible to reëlection without limitation."

### *PROPOSED AMENDMENT TO THE BY-LAWS*

The Secretary also stated that the Council recommended the following change in the By-Laws:

To amend chapter VII, section 1, by omitting the words "of moneys paid by the general public for publications of the Society," so that the section shall read: "1. The Publication Fund shall consist of donations made in aid of publication and of the sums paid in commutation of dues, according to the By-Laws, chapter I, clause 2."

The Council also announced, through the Secretary, that on account of the depleted condition of the treasury it would not be possible to print many of the papers read at this meeting, and a close selection would be necessary.

The presentation of papers was resumed, and the following three papers were read by title:

*PROCESS OF SEGREGATION AS ILLUSTRATED IN THE NEW JERSEY HIGHLANDS*

BY RALPH S. TARR

*ALUNOGEN AND BAUXITE OF NEW MEXICO, WITH NOTES ON THE GEOLOGY OF THE UPPER GILA REGION*

BY WILLIAM P. BLAKE

*USE OF THE ANEROID BAROMETER IN GEOLOGICAL SURVEYING*

BY CHARLES W. ROLFE

The following paper was read by the author:

*PLATYCNEMIC MAN IN NEW YORK*

BY WILL H. SHERZER

The following three papers were read by title:

*OIL AND GAS IN KANSAS*

BY ERASMUS HAWORTH

*FAULTS OF THE REGION BETWEEN THE MOHAWK RIVER AND THE ADIRONDACK MOUNTAINS*

BY N. H. DARTON

*THE DRUMLINOID HILLS NEAR CAYUGA, NEW YORK*

BY RALPH S. TARR

The following paper was presented in abstract by J. P. Smith:

*REVIEW OF OUR KNOWLEDGE OF THE GEOLOGY OF THE CALIFORNIA COAST RANGES*

BY HAROLD W. FAIRBANKS

This paper is printed in full in this volume.

The following three papers were read by title:

*GEOLOGICAL HISTORY OF MISSOURI*

BY ARTHUR WINSLOW

*THE MAGNESIAN SERIES OF THE NORTHWESTERN STATES*

BY C. W. HALL AND F. W. SARDESON

This paper, which was read at the Madison meeting and was to have been printed in volume 5,* will be printed in full in this volume.

*STRATIGRAPHY OF THE SAINT LOUIS AND WARSAW FORMATIONS IN SOUTH EASTERN IOWA*

BY CHARLES H. GORDON

In the absence of the author, the following paper was presented in abstract by H. S. Williams:

*KANSAS RIVER SECTION OF THE PERMO-CARBONIFEROUS AND PERMIAN ROCKS OF KANSAS*

BY CHARLES S. PROSSER

This paper is printed in full in this volume.

The following paper was read by title:

*CENOZOIC HISTORY OF A PORTION OF THE MIDDLE ATLANTIC SLOPE*

BY N. H. DARTON

In the absence of the author, the next paper was presented in abstract by G. H. Barton.

*TERTIARY AND EARLY QUATERNARY BASELEVELING IN MINNESOTA, MANITOBA, AND NORTHWESTWARD*

BY WARREN UPHAM

[*Abstract*]

*Contents*



## Baseleveling of the Cretaceous northwestern Plains during the Tertiary Era.

From the valleys of the Mississippi and Minnesota rivers, the Red river of the North, and lake Winnipeg, a broad area of plains ascends gradually westward to the foot of the front ranges of the Rocky mountains. The first ascent from the

*See volume 5, page 7.

Minnesota and Red river valleys and from the flat country inclosing lakes Winnipeg, Manitoba, and Winnipegosis, is mainly by an abrupt escarpment eroded in the Cretaceous strata forming the eastern border of the plains. The altitude of these valleys and of the Manitoba lake region ranges from 1,000 to 750 feet above the sea, and the escarpment, which, as viewed from the lowlands on the east, is named in its successive portions from south to north the Coteau des Prairies, the Pembina, Riding and Duck mountains, and the Porcupine and Pasquia hills or mountains, rises from 200 or 300 feet to 1,000 feet within a few miles, its crest being mostly 1,500 to 2,000 feet above the sea-level. Thence westward the expanse of the plains, broken here and there by eroded valleys and tracts of sometimes very irregular denudation, has nevertheless for the greater part a very uniform nearly flat or moderately rolling surface, which rises on the average four or five feet per mile to a height somewhat exceeding 4,000 feet above the sea at the foot of the Rocky mountains in Montana and Alberta, on the opposite sides of the United States and Canadian international boundary.

The geologic strata of this northern part of the great plains are the Dakota, Colorado, Montana and Laramie formations of late Cretaceous age, whose deposition took place during the closing part of the Secondary or Mesozoic era. Since the beginning of the Tertiary era this region has been a land surface undergoing denudation. When its marine and lacustrine deposits were first raised to be dry land they had a monotonously flat surface. A very long cycle of baseleveling ensued, beginning as soon as this northern part of the plains was uplifted at the end of Cretaceous time and continuing nearly or quite to the end of the Tertiary era. During this time the surface was gradually lowered by the action of rains, rills, rivulets, creeks and rivers, until it was mostly reduced to a baselevel of subaërial erosion.

### Areal and vertical Extent of the Baseleveling.

Across an area 700 or 800 miles wide from east to west on the international boundary and of much greater extent from south to north the processes of baseleveling were at work through the vast duration of Tertiary time; but here and there isolated areas of hills and even mountains remain, consisting of remnants of the horizontal Cretaceous strata which elsewhere have suffered erosion. The most noteworthy eastern highland area of this kind is the Turtle mountain, lying in the north edge of North Dakota and the south edge of Manitoba, its extent on the boundary being about 40 miles, with two-thirds as great width. Its altitude above the surrounding country is 300 to 800 feet, the summits of its highest hills being about 2,500 feet above the sea. Beneath a veneering of glacial drift, which is in large part morainic and generally strewn with many bowlders, averaging perhaps 50 to 75 feet in thickness, Turtle mountain consists of nearly horizontally bedded Laramie strata, chiefly shales, with very thin seams of lignite. At or below the base of this highland the fresh-water Laramie formation rests on the marine series, which comprises the Fox Hills sandstone and Fort Pierre shales, the two great shale formations being separated by a sandstone stratum which outcrops in North Dakota on Ox creek and Willow river and on the Souris river between Minot and its most southern bend. A thickness of not less than 500 to 1,000 feet of the Laramie and Montana (Fox Hills and Fort Pierre) strata has been carried away from the surrounding eastern part of the plains.

Westward the depth of the Tertiary baseleveling was greater. Around the Highwood and Crazy mountains, in central Montana, according to Professor W. M. Davis * and Dr J. E. Wolff,† the erosion of the plains has a vertical extent of 3,000 to 5,000 feet. Perhaps the most striking evidence of this great erosion is afforded by the range of the Crazy mountains, which lies immediately north of the Yellowstone river near Livingston and is conspicuously seen from the Northern Pacific railroad. These mountains trend slightly west of north, and extend about 40 miles with a width of 15 miles, attaining an elevation of 11,178 feet above the sea and 5,000 to 6,000 feet above the prairies at their base. Their structure has been thoroughly studied by Wolff, who finds that they consist of late Cretaceous strata, soft sandstones, nearly horizontal in stratification, intersected by a network of eruptive dikes. The more enduring igneous rocks have preserved this range, while an average denudation of not less than one mile in vertical amount reduced all the adjoining region to a baselevel of erosion. The Highwood mountains, about 25 miles east of Great Falls, having a height of 7,600 feet above the sea or about 3,000 feet above their base, are described by Davis as displaying the same structure, and therefore similarly testifying of great denudation.

The uplift at the beginning of the Tertiary era appears to have raised this portion of the plains to a height above the sea as great as the vertical extent of their Tertiary erosion—that is, to a height of at least 1,000 to 5,000 feet, increasing from east to west. Toward the end of this era the baseleveling had reduced the country mostly to a plain, which was probably only a few hundred feet above the sea, lying much below its present altitude.

### Renewed Elevation and partial Baseleveling at the Close of the Tertiary and during the early Part of the Quaternary Era.

Between the general Tertiary cycle of baseleveling and the Glacial period there ntervened a second great epeirogenic uplift, as shown by a return of the conditions of vigorous stream erosion and a new cycle of partial baseleveling, by which wide flat valleys were cut in the eastern part of these Cretaceous plains. In Manitoba the northeastern border of the formerly baseleveled expanse was removed, the Cretaceous beds being eroded to the underlying Archean and Paleozoic rocks upon a large area bounded on the west by the escarpment before mentioned as forming the eastern limit of the plains. The duration of the earlier baseleveling apparently coincided as to both beginning and end with the Tertiary or Somerville cycle of partial baseleveling which Davis and Wood have studied in Pennsylvania and northern New Jersey and believe to have affected a large area of the other eastern states.‡

East from the foot of the Pembina, Riding and Duck mountains and the hills farther north, together called the Manitoba escarpment by Mr J. B. Tyrrell, of the Canadian Geological Survey, Cretaceous strata have not been found, so far as I have learned, in Manitoba, nor in the region north and northeast from lake Winnipeg to Hudson bay. It seems quite certain, however, that Cretaceous beds continuous from this escarpment extended eastward at the end of the Tertiary base-

* Mining industries of the United States, Tenth Census, vol. xv, pp. 710, 737, 745.

† Bulletin, Geol. Society of America, vol. iii, 1892, pp. 445–452.

‡ Proceedings Boston Society of Natural History, vol. xxiv, 1889, pp. 365–423; National Geographic Magazine, vol. i, 1889, pp. 183–253; vol. ii, 1890, pp. 81–110.

leveling so far as to cover the area of lake Winnipeg. As Hind and Dawson have well pointed out, it was by the erosion of the eastern portion of these beds, after the great western expanse of the plains had received nearly its present form, that this steep escarpment was produced.* At the time of uplifting of the plains, near the beginning of the Quaternary era, this great baseleveled region appears to have stretched from the Rocky mountains to the Archean hills on the eastern border of the area of the later glacial lake Agassiz. The east margin of the soft Cretaceous strata was then anew subjected to rapid erosion, with the result that it was almost wholly worn away to the floor of Archean gneiss and granite and the Paleozoic limestones upon a width of 100 miles or more and to a depth westward of 300 to 1,000 feet, as shown by the height of the Pembina mountain and Manitoba escarpment.

In Minnesota and North Dakota the flat Red river valley plain, averaging 50 miles wide, with a depth of 200 to 500 feet below the country on each side, and extending more than 200 miles from south to north, opening into the Manitoba lake area, appears also to have been eroded at the same time. The conspicuous Pembina mountain escarpment of Cretaceous shales, overspread by drift, on the west side of this valley, deep wells penetrating through the drift to Cretaceous beds and older strata along the low valley plain, and the topographic features of the land rising eastward from it, with nearly the same rate of ascent as on the west, lead to the belief that the eastern, like the western, border of this wide valley is formed by an escarpment of Cretaceous shales beneath the drift. The baseleveled plain of the Tertiary era has been broadly and deeply channeled during a later time of high continental uplift.

### Relationship of the later Baseleveling to the Ice Age.

Flowing so great distances before reaching the sea, the rivers of both these cycles of baseleveling may have denuded their areas of drainage, during the first cycle very completely and during the second partially, to broad plains, while yet the altitude of the Manitoba lake region equaled or exceeded that of the present time. Lake Winnipeg is 710 feet and lake Manitoba 809 feet above the sea. Newly uplifted as a high plateau during the early portion of the Quaternary era, this north part of the continent, rising probably somewhat faster in the Arctic region than farther south, may have continued to present favorable conditions for the baseleveling of the Red river valley and the district of the great Manitoba lakes until the mean altitude of the area which became covered by the North American ice-sheet and its drift was 3,000 to 5,000 feet higher than now, as indicated by the fjords and submarine valleys of our northern Atlantic, Arctic and northern Pacific coasts. The culmination of this uplift appears to have brought such cold and snowy climate that a vast sheet of snow and ice was gradually accumulated, under whose weight the land finally sank mostly somewhat below its present height, causing the ice-sheet to be melted away, with deposition of its glacial and modified drift.

This paper is published in full in the American Geologist, vol. xiv, October, 1894, pp. 235–246.

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* H. Y. Hind, Report of the Assiniboine and Saskatchewan Exploring Expedition, Toronto, 1859, pp. 168, 169; Narrative of the Canadian Exploring Expeditions, London, 1860, vol. ii, pp. 48, 55, 265. G. M. Dawson, Geology and Resources of the Forty-ninth Parallel, 1875, pp. 253, 254.

The next paper, by the same author, was read by title:

## *DEPARTURE OF THE ICE-SHEET FROM THE LAURENTIAN LAKES*

BY WARREN UPHAM

[*Abstract*]

*Contents*



### PHENOMENA ATTENDING THE RETREAT OF THE CONTINENTAL GLACIER.

The glacial drift reveals to us far more of the history of the Champlain epoch or time of general retreat of the ice-sheet with deposition of its drift and accumulation of its retreatal moraines than all which we can learn concerning the oncoming and culmination of the Ice age. During this closing Champlain epoch of the Glacial period lakes of great extent, held in on their northern and northeastern or iceward sides by the barrier of the gradually waning and departing ice-sheet, existed in the valley of the Red river of the North and the basin of the great lakes of Manitoba and in the basins of the Laurentian lakes, Superior, Michigan, Huron, Erie, Ontario and Champlain. The glacial lake Agassiz, attaining an area of more than 100,000 square miles, occupied the Red river valley and a large part of Manitoba, and the similar but smaller lakes Warren, Algonquin, Iroquois and Hudson-Champlain, in part successive and in part contemporaneous with one another, filled the basins of the great lakes now outflowing by the Saint Lawrence, their ancient shorelines, with beaches and deltas, being much higher than the present lake levels. The uplift of the area of lake Agassiz was practically completed during the Champlain epoch or time of the glacial retreat, as is known by the horizontality of its lowest and latest beaches, whereas its highest and earliest shores have received an inclination of ascent northward averaging about one foot per mile along their observed extent of 400 miles.* In like manner, but with greater

*"Wavelike Progress of an Epeirogenic Uplift," Journal of Geology, vol. ii, pp. 383-395, May-June, 1894.

complexity, the shorelines of the glacial predecessors of the Laurentian lakes were uplifted with varying gradients, so that now, in connection with the history of the successive channels of outlet opened by the retreat of the ice, they record the wave-like northeastward advance of a permanent uplift of that region from its Glacial and Champlain depression.

## Ancient high Shorelines in the western Part of the Basin of Lake Superior.

The upper limit of lacustrine action in Duluth and its vicinity, at the west end of lake Superior, is marked by discontinuous beach deposits on the upper part of the steeply ascending bluffs at an altitude of 535 to 540 feet above the lake. Another shore terrace of beach gravel and sand is at 515 to 505 feet, approximately. Next below these shorelines is the most definite and persistent beach of the entire series, both of the Western Superior lake and the ensuing lake Warren. This was generally represented along the bluff face by a narrow beach terrace or slight shelf carved and built up by the waves acting on the drift which thinly overlies the bed rock, less steep than the slopes below and above it, so that its contour line, 470 to 475 feet above the present lake, has been used as the course of a driveway, known as " the boulevard," which has been graded and is much used for pleasure driving, along an extent of four miles, above the principal part of the city of Duluth, from Millers creek to Chester creek. Beyond these limits the boulevard is planned to be extended for distances of four miles more both to the southwest and northeast, following the same altitude and shoreline, giving a total length of 12 miles. Its height is only a few feet above the water divide in the old channel of outflow from the Western Superior glacial lake past the head of the Bois Brulé river to the Saint Croix river;* but, if we make due allowance for the partial filling of that channel with postglacial alluvium and peaty swamp deposits, it seems probable that this latest shore of that glacial lake has now an ascent of 15 or 20 feet in the distance of about 25 miles from its outlet north-northwest to Duluth. The earlier and higher shores here were made when the erosion of the outlet lacked successively about 65 and 30 or 35 feet of its final depth; but a certain part of its earliest erosion had been done before the retreat of the ice extended the lake to this northwest coast.

Between the neighborhood of Duluth and mount Josephine, on the north coast of lake Superior, near Grand Portage, no definite observations of these three early shorelines have been obtained, although there can be no doubt that they extend continuously along this distance, which is about 130 miles in a nearly direct northeastward course. When the woods of this high coast shall be cleared off, as will probably some time be done in many places for farming and pasturage, the old lake levels will be observed, especially the highest and lowest of these three noted at Duluth. Attempting to correlate these beaches with those found by Dr A. C. Lawson † on mount Josephine, I identify the 535 feet and 515 to 505 feet Duluth shores as representing his 607 and 587 feet shores; and the 475 to 470 feet beach of the Duluth boulevard becomes apparently the conspicuous 509 feet beach of mount Josephine. The total differential uplifting of the two upper shores between these localities has been about 70 feet, of which about half had been accomplished previous to the time of the Boulevard beach.

* Proc. Am. Assoc. Adv. Sci., vol. xxxii, for 1883, p. 230; Geology of Minnesota, vol. ii, 1888, p. 642; Bulletin Geol. Society of America, vol. ii, 1891, p. 258.

† Geol and Nat. Hist. Survey of Minnesota, Twentieth An. Rep., for 1891, pp. 251–253.

Eight lower shorelines, formed after the Western Superior lake was merged with the more extensive lake Warren, are marked in and near Duluth by small beach ridges on portions of the old lake shores situated favorably for their accumulation, and by deltas of inflowing streams. A fine succession of these deltas was observed along the course of Chester creek, through the city of Duluth, in its descent from its high valley cut in the upper part of the bluffs. To present concisely the results of my studies for the Minnesota Geological Survey* of the whole series of lake shores observed by me in the vicinity of Duluth and their probable correlations with the shores observed farther eastward by Dr A. C. Lawson,† Mr F. B. Taylor,‡ Professor J. W. Spencer § and others, they are arranged a little farther on in their descending order, with notes of their altitudes at numerous places in feet above lake Superior. The observations along the north coast of this lake are by Dr Lawson; on Isle Royale and in part on the Keweenaw peninsula, by Dr A. C. Lane, from unpublished work for the Michigan Geological Survey; and along the southern coast of lake Superior, about Green bay of lake Michigan and eastward to lake Nipissing, by Mr Taylor. On northern portions of the lake Superior coast several of these old lake levels seem to be each represented by two or more shores, separated by vertical intervals of 10 feet or more. Most of the beaches, it should be remarked, are very feebly developed, even in the most favorable localities for their formation, and are not discernible along the greater part of all the lake borders.

##### BEACHES OF THE WESTERN SUPERIOR GLACIAL LAKE AND THEIR ALTITUDES

*First Duluth Beach.*—At Duluth, 535 feet above lake Superior; on mount Josephine, 607 feet; at Kimball, Wis., 570 feet; and at L'Anse and Marquette, Mich., 590 feet.

*Second Duluth Beach.*—At Duluth, 515-510 feet; on mount Josephine, 587 feet.

*Boulevard Beach.*—At Duluth, 475–470 feet; on mount Josephine, 509 feet.

##### BEACHES OF THE GLACIAL LAKE WARREN AND THEIR ALTITUDES

*Belmore Beach.*—This name was given by Professor N. H. Winchell to the corresponding earliest shoreline of lake Warren in Ohio. Near Wrenshall and in Duluth, 410–415 feet; Grand Portage, 440 feet; on the Kaministiquia river, 455 feet; at Mackenzie, on the Canadian Pacific railway 13 miles northeast of Port Arthur, Dr Lawson's descriptions indicate that this lake level, at about 475 feet, adjoined the melting ice-sheet (l. c., page 264); eight miles east of Cartier, about 600; southeast of lake Nipissing, 605–620. The Ridgeway beach of Professor Spencer.

*Nelson Beach.*—Named by Taylor in the vicinity of North Bay, lake Nipissing; probably united with the Belmore beach in Ohio and northward to Mackinac island. At Duluth, 385 feet; at Mackenzie, a morainic terrace, 420 feet; at Jackfish bay, 418 feet; at Cook's mill, north of Green bay, lake Michigan, 150 feet;

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* Geol. and Nat. Hist. Survey of Minnesota, Twenty-second An. Rep., for 1893, pp. 54–66.

† "Sketch of the Coastal Topography of the North Side of Lake Superior, with special reference to the Abandoned Strands of Lake Warren," Minnesota Twentieth An. Rep., pp. 181–289, with plates, map and sections.

‡ "The Ancient Strait at Nipissing," Bulletin Geol. Society of America, vol. v, pp. 620–626, April 1894; "Reconnaissances of the Abandoned Shorelines of Green Bay and of the South Coast of Lake Superior," Am. Geologist, vol. xiii, pp. 316–327 and 365–383, with maps, May and June, 1894.

§ Am. Jour. of Science, Dec., 1890, Jan. and March, 1891, and March, 1894; Bulletin Geol. Society of America, vol. ii, pp. 465–476, April, 1891. All these articles are accompanied with maps.

about the south part of this bay, nearly at the level of lake Superior; at Houghton, on the Keweenaw peninsula, 410 feet; Sault Ste. Marie, 414 feet; North bay, 538 feet.

*McEwen Beach.*—Named by Taylor near North Bay. At Duluth, 350 feet; Schreiber and Terrace bay, 391–2 feet; Sault Ste. Marie, 365 feet; North Bay, 488 feet.

*Thibeault Beach.*—Named also by Taylor near North Bay. Great Northern railway, about two and a half miles northeast of Foxboro, near the line between Minnesota and Wisconsin, 290–300 feet; mount Josephine, 313 feet; Mackenzie, 327 feet; Sault Ste. Marie, 311 feet.

*Double Bay Beach.*—At Duluth, 255-260 feet; at Double bay, 279 feet; on Isle Royale, about 270 feet; Carp river, 288 feet.

*First Beaver Bay Beach.*—At Duluth, 155–160 feet; at Beaver bay, 173 feet; eastward represented by two beaches: (*a*) at Grand Portage, 232 feet; at Carp river and Pie island, 222 feet; at Terrace bay, 243 feet; at Sault Ste. Marie, 224 feet; on the Keweenaw peninsula, 220 feet; (*b*) at Mazokamah, 214 feet; Terrace bay, 228 feet; Dog river, 216 feet; Sault Ste. Marie, 208 feet; on the Keweenaw peninsula, about 200 feet.

*Second and third Beaver Bay Beaches.*—Become three northeastward: At Duluth, 85–90 feet; Beaver bay, 126 and 115 feet; Pigeon river (third), 134 feet; Isle Royale, about 130 feet; shore above Carp river, 164, 128 and 122 feet; Port Arthur (third), 149 feet; Silver islet, 168, 161 and 149 feet; Jackfish bay, 176 and 158 feet; Sault Ste. Marie, 150 feet; Keweenaw peninsula, 170, 150 and 145–125 feet (delta of Huron creek, A. C. Lane).

*Chester Creek Beach.*—At Duluth, 45–50 feet; Beaver bay, 80 feet; Isle Royale, 90 feet; McKellar's point, 101 feet; Port Arthur, 118 feet; Nipigon, 132 feet; Montreal river, 135 feet; Mackenzie, 122 feet.

### *BEACH OF THE GLACIAL LAKE ALGONQUIN AND ITS ALTITUDES*

Lake Algonquin, and its highest shoreline, the *Algonquin beach*, which is here noted, were named by Professor J. W. Spencer.* At Duluth the Algonquin beach is united with the present lake beaches; at Beaver bay its height is 20 feet; Good Harbor bay, 27 feet; Grand Portage, 38 feet; McKellar's point, 48 feet; Carp river, 52 feet; Pie island, 43 feet; Port Arthur, Nipigon and Montreal river, 61 feet; Houghton and Marquette, about 25 feet; Sault Ste. Marie, 49 feet; near Algoma, 60–80 feet; near North Bay, on lake Nipissing, 140 feet. The Nipissing beach of Mr Taylor, but not his "Algonquin beach" on Mackinac island,† which is the highest of the lake Warren shores, being apparently the compound representative of the Belmore and Nelson beaches.

### WESTERN SUPERIOR GLACIAL LAKE

The front of the departing ice-sheet was the barrier of the Western Superior glacial lake, while the one receded and the other advanced from Duluth northeastward to mount Josephine and the most northeastern point of Minnesota and eastward to Marquette. When the farther glacial recession opened the space for this lake and the similarly expanding lake Warren to be merged together above the

* Proc. Am. Assoc. Adv. Sci., vol. xxxvii, 1888, p. 199.
† Am. Jour. Sci., III, vol. xliii, March, 1892, pp. 210–218.

low land of the eastern part of the Michigan upper peninsula, the Western Superior waters fell 50 feet or more below their former outlet to the Saint Croix and Mississippi rivers, and thenceforward the outlet of lake Warren past Chicago to the Mississippi, by way of the Des Plaines and Illinois rivers, carried away the drainage from the glacial melting and rainfall of the lake Superior basin.

### Lake Warren

At a time that was probably somewhat later than the end of the Western Superior lake, its analogue, the Western Erie glacial lake, which had outflowed past Fort Wayne, Indiana, to the Wabash, Ohio and Mississippi rivers, became likewise lowered and merged in lake Warren, which in its soon ensuing maximum stage stretched from the south end of lake Michigan to the north side of lake Superior, northeast to lake Nipissing, and eastward to the east end of lake Erie and the southwestern limits of the lake Ontario basin. The river outflowing from lake Warren probably cut down its channel 50 feet or more into drift which had been deposited in the rock valley of the Des Plaines river in the vicinity of Willow Springs and Lemont, between 15 and 30 miles southwest of Chicago. The mouth of the lake was thus reduced in height and transferred upstream, until, at the end of the duration of this outflow and of the glacial lake Warren, the drift-covered divide in the old channel, situated near Summit and the elbow of the Des Plaines, about 10 miles southwest from the shore of lake Michigan at Chicago,* was only seven or eight feet above the present mean lake level. While the outlet continued here, all the northern part of the area of lake Warren, extending about 600 miles from Duluth to lake Nipissing, was uplifted about 350 to 400 feet.

### Lake Algonquin

When the glacial melting and retreat at length permitted an outflow from the Saint Lawrence basin over a lower pass, which was through central New York to the Mohawk and Hudson, the water surface in the basins of lakes Michigan, Huron and Superior fell only some 50 or 75 feet from the latest and lowest stage of lake Warren to its short-lived successor, lake Algonquin. This lake was ice-dammed only at low places on its east end, as at or near the heads of the Trent and Mattawa rivers, lying respectively east of lakes Simcoe and Nipissing, where otherwise its waters must have been somewhat further lowered to outflow by those passes. A careful study of the late glacial or Champlain epeirogenic uplifting of all portions of the Saint Lawrence drainage area, as known by the present inclinations of its many shorelines, convinces me that Gilbert † and Wright ‡ have overestimated the importance of the outflow, if any such took place, from lake Algonquin past the present lake Nipissing to the Mattawa and Ottawa rivers. Professor Spencer's Algonquin beach is very clearly the Nipissing beach of Mr Taylor, and this earliets

* For information concerning this locality, and for a map and profiles of the canal now being constructed past it with continuous descent away from the lake, I am indebted to Mr Ossian Guthrie, of Chicago, who has bestowed much study on the glacial drift and Pleistocene history of that region.

† "History of the Niagara River," Sixth An. Rep. of the Commissioners of the State Reservation at Niagara, for the year 1889, pp. 61–84, with eight plates (also in the Smithsonian Annual Report for 1890).

‡ Bulletin Geol. Society of America, vol. iv, 1893, 423–427.

and principal stage of lake Algonquin is shown by these beaches to have coincided closely in area with lakes Michigan and Superior, but to have been considerably more extensive eastward than the present lake Huron and Georgian bay. It held a level which now by subsequent differential epeirogenic movements is left probably wholly below the level of lake Michigan by a vertical amount ranging from almost nothing to about 40 feet. Its shores were nearly coincident with the western shore of lake Huron, but eastward they are now elevated mostly 150 to 200 feet above that lake and Georgian bay, and in the lake Superior basin they vary from about 50 feet above lake Superior at its mouth and along its northeastern and northern shores to 25 feet at Houghton, and to a few feet or none at Duluth. The earliest outflow of lake Algonquin appears to have passed southward by the present course of the Saint Clair and Detroit rivers; thence it ran east as a glacial river Erie, following the lower part of the bed of the present lake Erie, which then had an eastward descent of probably 200 feet, allowing no lake or only a very small one to exist in the deepest depression of the basin; and north of Buffalo it coincided with the course of the Niagara river.

### Order of Recession of the Ice-sheet territorially

The recession of the ice-sheet from the area of lakes Warren and Algonquin was earlier than from the lake Ontario or Iroquois basin and the country eastward to the New England coast.

During the time of formation of the high Belmore and Nelson beaches of lake Warren, this glacial-lake, outflowing at Chicago, stretched northward to the north side of lake Superior and northeastward to lake Nipissing. With lake Warren of this extent, the ice-sheet had melted off from all the northern United States west of lake Nipissing and of Buffalo, New York; but yet, to form a barrier on the east, it remained unmelted upon all the Niagara and lake Ontario or Iroquois area. Thus we see that all the moraines within the limits of the United States west of the great angle of the drift boundary near Salamanca, in southwestern New York,* are somewhat older than the moraines east of that angle in New York, Pennsylvania, New Jersey, Long island and New England. This difference in age, however, between the western and eastern moraines and drift was perhaps no more than 500 to 1,000 years, as we may infer from the rate of retreat of the portion of the ice-front forming the northern barrier of the glacial lake Agassiz.

This unexpected view of the order of departure of the ice-sheet finds meteorologic explanation as follows: The melting of the vast western part of the ice-sheet in the United States, from North Dakota and Minnesota east to the lake Erie basin, would supply to our eastwardly moving storms a very great amount of moisture to be precipitated farther east. That precipitation I think to have been mainly snow, as these storms, moisture-laden from the western ice-melting, swept over the more eastern part of the ice-sheet. Hence the eastern great ice-lobe from Salamanca to Long island, Cape Cod, and the gulf of Maine, would be fed and thickened and spread in some places even beyond its previous limits, while all of the ice-sheet farther west in the United States was being melted away. †

* Consult Professor Chamberlin's maps of the glaciated areas of the United States, U. S. Geol. Survey, Third Annual Report, plates xxviii and xxxiii; Seventh An. Rep., plate viii.

† For evidence of similar but smaller climatic effects on the waning ice-sheet in Minnesota see Proc. Am. Assoc. Adv. Sci., vol. xxxii, for 1883, pp. 231–234, and Geology of Minnesota, vol. ii, 1888, pp. 254–256, 409–413.

### Character and Progress of the Uplift following Recession of the Ice-sheet

A wave-like uplift from the Champlain subsidence advanced to the area of lakes Iroquois and Hudson-Champlain after it was nearly or quite completed in the area of lake Warren.

In previous discussions of the relationships of these glacial lakes * I have stated more fully than can be attempted in this paper the stages of advance of the gradual upward movement of their areas in its progress from south to north and from southwest to northeast, *pari passu* with the recession of the ice-sheet in the same directions. Closely following the ice-border in its retreat, there ensued an uplift of the northern part of the region covered by lake Warren to a total amount of 400 to 600 feet, of which the greater part, ranging from seven-eighths of the whole 400 feet at Duluth to about two-thirds of the whole 600 feet at lake Nipissing, had taken place before the time of the Algonquin or Nipissing beach. The continuation of this uplift during the time of accumulation of the lower beaches of lake Algonquin probably raised the area of the watershed between lake Nipissing and the Mattawa river to so great an altitude as to forbid outflow there previous to the removal of the ice barrier from the Mattawa and Ottawa basins on the east.

Like the uplift of the lake Agassiz area, first at the south, later in its central part, and latest at the north, so the region of the Laurentian lakes appears to have been elevated nearly or quite to its present level, first from Duluth east to lake Nipissing and Buffalo, and afterward, while the ice barrier of lake Iroquois was retreating, the basins of lakes Ontario and Champlain were raised approximately to their present altitude. The maximum gradient of the earlier part of the uplift of the Saint Lawrence basin was about five feet per mile from south to north upon portions of the Michigan upper peninsula; and an equally large differential movement gave to the Iroquois beach an ascent of nearly 300 feet in 55 miles from south to north between Rome and the latitude of Watertown, New York. The correlative maximum northward uplifting of the shorelines of lake Agassiz is found by Mr J. B. Tyrrell along the eastern base of Riding and Duck mountains, in the north central portion of that lake's entire extent, being about three feet per mile. After the lake Iroquois area had received the greater part of its re-elevation from the Champlain subsidence, the more northern Ottawa and Saint Lawrence valleys were upraised to a maximum amount exceeding 500 feet at Montreal. From south to north and northeast a wave of epeirogenic upward movement advanced upon the region of the Laurentian lakes and to Montreal, nearly contemporaneous with the uplift of the valley of the Red river of the North, of Manitoba, and of the country thence northeast to Hudson bay.

The acting President declared the scientific program closed.

Professor Joseph Le Conte moved that the thanks of the Society be extended the trustees and officers of the Packer Institute for the use of rooms, and to the Local Committee of the American Association for the Advancement of Science for the preparations and facilities for the meeting. It was unanimously voted.

* Bulletin Geol. Society of America, vol. ii, 1890, pp. 258–265; vol. iii, 1891, pp. 484–487 and 508–511.

Professor W. B. Scott asked permission to present the following—

### *NOTE ON FLORENTINO AMEGHINO'S LATEST PAPER ON PATAGONIAN PALEONTOLOGY*

BY W. B. SCOTT

I desire to call attention briefly to Ameghino's latest paper, "Enumération synoptique des espèces de mammifères fossiles des formations Éocènes de Patagonie," Buenos Aires, 1894, that contains some very important facts for the estimation of the geologic age of the Patagonian Tertiary formations, which have yielded such an abundant and interesting mammalian fauna. The Santa Cruz beds are now proved to overlie the "Patagonian" beds instead of underlying them.

Ameghino still maintains the Eocene age of these beds, but European and North American paleontologists have repeatedly pointed out the modern character of their mammals and have referred them to the Miocene. The latter view is definitely confirmed by the occurrence of true whales (*Balæna*) in the "Patagonian" beds. The extraordinary isolation and peculiarity of this fauna offers few other terms for direct comparison with the Miocenes of the northern hemisphere.

The Sixth Summer Meeting was then declared adjourned.

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## Register of the Brooklyn Summer Meeting

The following Fellows were in attendance upon this meeting:

F. D. Adams.
G. H. Barton.
Samuel Calvin.
B. K. Emerson.
H. L. Fairchild.
A. E. Foote.
A. C. Gill.
C. H. Hitchcock.
C. A. Hollick.
Jed Hotchkiss.
E. O. Hovey.
H. C. Hovey.
E. E. Howell.
J. F. Kemp.
A. C. Lane.
Joseph Le Conte.
W J McGee.
F. J. H. Merrill.
F. H. Newell.
W. N. Rice.
Heinrich Ries.
W. B. Scott.
N. S. Shaler.
W. H. Sherzer.
J. P. Smith.
J. W. Spencer.
J. J. Stevenson.
A. S. Tiffany.
I. C. White.
R. P. Whitfield.
H. S. Williams.

*Fellows-elect*

Florence Bascom.
D. F. Lincoln.
L. G. Westgate.

Total attendance, 34.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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# KANSAS RIVER SECTION OF THE PERMO-CARBONIFEROUS AND PERMIAN ROCKS OF KANSAS*

BY CHARLES S. PROSSER

(*Read before the Society August 15, 1894*)

CONTENTS



* Published by permission of the Director of the United States Geological Survey.

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## Introduction.

Along the upper course of the Kansas or Kaw river, in the northern part of eastern Kansas, are good exposures of the rocks belonging to the Permo-Carboniferous and Permian systems. The early students of the geology of the state—Meek, Hayden, Swallow, Hawn, and later St. John—clearly recognized the importance of this section, although there was a decided difference of opinion among them regarding the structure and correlation of the rocks.

The strongest feeling that has ever existed in reference to any question concerning the geology of Kansas was developed by this controversy, and now that most of the participants in the discussion have passed away, it is interesting to review the arguments and compare them with our present knowledge of these formations. Later writers apparently have not considered to any extent the descriptions of this section, and on this account it also seems advisable to call attention to this early work.

## Review of Previous Work.

### *MEEK AND HAYDEN'S EXPLORATION OF 1858.*

In the summer of 1858 Mr F. B. Meek and Dr F. V. Hayden studied the Paleozoic rocks of northeastern Kansas, and in January, 1859, published an interesting account of their observations.*

Their route was from Leavenworth, first to the southwest, reaching the Kansas river valley near the mouth of Soldier creek and North Topeka; then up the north side of the Kansas and Smoky Hill rivers to the mouth

* Proc. Acad. Nat. Sci., Philadelphia, vol. xi, pp. 8-30.

of Solomon river; then they crossed to the south side of the Smoky Hill river, followed it to a point near the western boundary of McPherson county, thence east to the head of the Cottonwood valley, which was followed nearly as far as Cottonwood Falls; then across the divide through Council Grove and Lost Springs to the Smoky Hill river near the mouth of Solomon river, and finally the course was down the south side of the Smoky Hill and Kansas rivers to Lawrence, where they crossed the Kansas river and returned to Leavenworth.

Between Leavenworth and Manhattan a number of local sections are described and the thickness of the different layers indicated, with lists of the characteristic fossils, but no continuous general section is given until the mouth of the Big Blue river is reached at Manhattan. From this point the authors state:

"As our examinations along the Kansas and Smoky Hill rivers . . . were made in more detail, where the outcrops were more frequent and continuous we have, as we believe, been able to trace out the connections and order of succession of the various strata with considerable accuracy."*

Then follows what is called a "General section of the rocks of Kansas valley from the Cretaceous down, so as to include portions of the upper Coal Measures," which is composed of forty beds.† Number one is the Dakota sandstone on the summit of the Smoky hills, and the order is descending until number 40, composed of Carboniferous shales, is reached, opposite the mouth of the Big Blue river. A brief description of the geologic characters is given; also lists of common fossils and thickness and location of the different beds.

### *SWALLOW'S REPORT.*

In 1866 Professor G. C. Swallow, state geologist of Kansas, published a "Preliminary Report of the Geological Survey of Kansas, which contains a section of the rocks in eastern Kansas."‡ This section begins with the Quaternary, which is called system I. The base is the lower Carboniferous or formation *C* of the Carboniferous, which is system VI. The Permian rocks constitute system V, which is divided into the upper and lower Permian,§ and includes numbers 12 to 84 of the general section. The statement is made that the base of the lower Permian is

* Ibid., p. 15.

† Ibid., pp. 16–18. This section is quoted by Dr Newberry in Report upon the Colorado river of the West, expedition in 1857–'58 of Lieutenant Joseph C. Ives, pt. iii, Geol. Rep. by J. S. Newberry, 1861, pp. 112–114.

‡ Pp. 9–29. This section was also published in Proc. Am. Asso. Adv. Science, vol. 15, 1867, pp. 57–75.

§ This division is made in the part termed the "Geology of Kansas," pp. 42, 43, although in the section the "Upper" is called "the Permian strata," pp. 11, 12, numbers 12 to 30, and then follows the "Lower Permian," pp. 12–16, numbers 31 to 84.

shown at Manhattan and on Mill creek, some twenty miles southeast of Manhattan. Professor Swallow insisted that the Mill Creek section showed an unconformity, and that numbers 84 to 95 of the sections near Manhattan were not found on Mill creek.*

Henry Engelmann, who was geologist of the exploring expedition of Captain J. H. Simpson across the Great plains and Great basin in 1859, gave some information in reference to the geology of this region. The details, however, refer mainly to the country some forty-five miles farther north, which was crossed by the expedition.†

## The Manhattan Geologic Section.

### *BROADHEAD'S SECTION.*

Before attempting to determine the position of the beds described by Meek and Hayden, and Swallow, it will be well to give a general description of the geologic section at Manhattan. Some ten years ago Professor G. C. Broadhead published a section of the rocks at Manhattan, which, in a condensed form, is as follows:

| | Feet. | Feet. |
|---|---|---|
| 1. Drab limestone | 4½ | = 208 |
| 2. Shaly slope | 30 | = 203½ |
| 3. Drab, compact, fine grained limestone | 3½ | = 173½ |
| 4. Chiefly shales to base of hill; a bed of red shale half way down | 170 | = 170‡ |

### *PROSSER'S SECTION.*

Near Manhattan are steep bluffs rising abruptly from the river to an elevation of more than 200 feet above the river level. Two of them stand out prominently—one, called Blue mount, just north of the city, and the other, to which Professor Broadhead's section refers, called mount Prospect, south of the Kansas river. An accurate section of the rocks of the region may be constructed from the outcrops on these two hills, although all of the layers are not well exposed on either mount. Blue mount rises very sharply from the Big Blue river, its summit being composed of the massive limestone, quarried so extensively about the city, which is called the Manhattan stone. On top of Blue mount is the city reservoir, the coping of which is 215 feet above low water in the Big Blue river and 10 feet higher than the top of the Manhattan stone. The following section was made on the east face of Blue mount:

* Op. cit., p. 44.

† Report Exploration across the Great Basin of the Territory of Utah in 1859 by Captain J. H. Simpson. Appendix I, Report on Geology of country between Fort Leavenworth, Kansas Territory, and the Sierra Nevada. Section I, Northeast Kansas and Southeast Nebraska, pp. 251–259.

‡ Trans. St. Louis Acad. Science, vol. iv, pt. iii, p. 491; read Nov. 6, 1882, and published in 1883 or 1884.

Reservoir level:

| | Feet. | Feet. |
|---|---|---|
| 6. Covered slope on Blue mount. At this horizon yellow shales containing plenty of fossils are exposed on mount Prospect, in the Uhlrich quarries up Wild Cat creek and at numerous other places about Manhattan. | 10 = | 215 |
| 5. Manhattan stone—a light yellowish gray, massive limestone containing a considerable amount of chert, and in the upper part great numbers of *Fusulina cylindrica*, Fischer. In the quarry at the top of mount Prospect it is 5 feet 4 inches in thickness. | 5 = | 205 |
| 4. Covered slope. On mount Prospect are shales, with some beds of laminated limestones about a foot in thickness. | 40 = | 200 |
| 3. At the top a drab to bluish limestone of irregular texture which weathers very unevenly. This layer is between 2½ and 3 feet in thickness on mount Prospect. On Blue mount it forms the first marked ridge, and the slope below the outcrop of this ledge is covered to the top of the road cut. | 64 = | 160 |
| 2. Yellowish, bluish and blackish shales, with thin layers of argillaceous limestone (6 inches to 1 foot in thickness). The limestone in the cut near railroad level is somewhat bluish and contains fossils. The blackish shales near the top of the railroad cut at its southern end contain numerous fossils. | 64 = | 96 |
| 1. Covered slope to level of Big Blue river........................... | 32 = | 32 |

### *COMPARISON OF FAUNAS.*

*Fauna at Foot of Blue Mount.*—The railroad cut, especially the blackish and yellowish shales in its upper part, afforded the following species:

1. *Productus cora*, d'Orbigny.* (*a*)
   This species is quite common in the yellowish shales.
2. *Productus longispinus*, Sowerby. (*c*)
3. *Productus nebrascensis*, Owen. (*r*)
4. *Productus semireticulatus* (Martin) de Koninck. (*rr*)
5. *Spirifer cameratus*, Morton. (*c*)
6. *Spirifer* (*Martinia*) *planoconvexus*, Shumard. (*aa*)
   This is a common species of the yellowish shales.
7. *Rhynchonella uta* (Marcou), Meek. (*c*)
8. *Hustedia mormonii* (Marcou), Hall and Clarke.† (*a*)
9. *Athyris subtilita* (Hall), Newb. (*c*)
10. *Chonetes granulifera*, Owen. (*c*)
11. *Chonetes glabra*, Geinitz. (*rr*)
12. *Discina manhattanensis*, M. and H. (*rr*)
    This species is not figured, but the specimen agrees with Meek and Hayden's description, and the original specimens came from the vicinity of this horizon at Manhattan.

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*The relative abundance of the species is indicated in the following manner: *a* = abundant; *aa* = very abundant; *c* = common; *r* = rare; *rr* = very rare, but one or two specimens found.

†The generic name *Hustedia* has recently been proposed by Hall and Clarke for the shell called *Retzia mormonii* (Marcou), Meek and Hayden (Pal. N. Y., vol. viii, pt. 2, fascicle i, July, 1893, p. 120).

13. *Lingula mytiloides*, Sowerby, or *L. umbonata*, Cox. (*r*)
    These species are difficult to distinguish.
14. *Derbya crassa* (M. and H.), H. and C. (*rr*)
15. *Meekella striato-costata* (Cox), White and St. John. (*rr*)
16. *Syntrilasma hemiplicata* (Hall), M. and W. (*rr*)
17. *Crania* sp. (*rr*)
18. *Allorisma subcuneata*, M. and H. (*rr*)
19. *Aviculopecten occidentalis* (Shum.), M. and W. (?). (*rr*)
20. *Nuculana bellistriata*, Stevens, var. *attenuata*, Meek (?). (*rr*)
21. *Dawsonella meeki*, Bradley (?). (*rr*)
22. *Lophophyllum proliferum* (McChesney), Meek. (*rr*)
23. *Synocladia biserialis*, Swallow. (*rr*)
24. *Fistulipora nodulifera*, Meek. (*c*)
25. *Rhombopora lepidodendroides*, Meek. (*rr*)
26. *Fusulina cylindrica*, Fischer. (*aa*)
27. *Fusulina cylindrica*, Fischer, var. *ventricosa*, M. and H. (*c*)
28. *Archæocidaris* sp., spines and plate. (*r*)
29. *Archæocidaris* sp., very large spine. (*rr*)
30. *Chætetes* sp. (*rr*)
31. *Phillipsia major*, Shumard (?). (*rr*)
    The glabella of the specimen. Although I have seen neither the figure nor the description of the glabella of *P. major*, it seems probable from the size and some other characteristics that it is this species.
32. *Crinoid*, fragments of stem. (*rr*)

*Fauna of Bed 37 of Meek and Hayden's Section.*—Meek and Hayden reported at 56½ feet above high-water mark of the Kansas river, opposite the mouth of the [Big] Blue river—

"Alternations of dark gray and blue soft decomposing argillaceous limestone, with dark laminated clays or soft shale containing great quantities of *Fusulina cylindrica*, *F. cylindrica*, var. *ventricosa*, *Discina manhattanensis*, *Chætetes*, and fragments of *Crinoids;* also *Chonetes verneuiliana*, *C. mucronata*, *Productus splendens* (?), *Retzia mormonii*, *Rhynchonella uta*, *Spirigera subtilita*, *Spirifer cameratus*, *S. planoconvexa*, *Euomphalus* near *E. rugosus*, and *Synocladia biserialis;* also *Cladodus occidentalis.*"*

This was number 37 of their section.

Since the above was written changes in synonymy have referred *Chonetes mucronata*, M. and H., to *C. granulifera*, Owen. *Productus splendens*, Norwood and Pratten, has been referred by Professor Meek and Dr White to *P. longispinus*, Sowerby. Dr Waagen has taken it for the type of the group which he called *Marginifera*, and in the latest work of Professors Hall and Clarke † it is called *P.* (*Marginifera*) *splendens*, N. and P., and *Spirigera subtilita* (Hall), M. and H., has been changed generically to *Athyris*.

* Proc. Acad. Nat. Sci., Philadelphia, vol. xi, p. 18.
† Eleventh Ann. Rep. State Geol. [New York], 1892, p. 223.

The list of fossils which I have given above is the result of two hours' collecting in the railroad cut, and the number of species would undoubtedly be increased by further search. Meek and Hayden reported *Chonetes verneuiliana*, N. and P.; *Euomphalus* cf. *rugosus*, Hall, and *Cladodus occidentalis*, Leidy, which I did not see, while my list contains the following additional species, viz:

*Productus cora*, d'Orbigny; *P. nebrascensis*, Owen; *P. semireticulatus* (Martin), de Koninck; *Chonetes glabra*, Geinitz; *Lingula mytiloides*, Sowerby (?); *Derbya crassa* (M. and H.), H. and C.; *Meekella striato-costata* (Cox), White and St. John; *Syntrilasma hemiplicata* (Hall), M. and W.; *Crania* sp.; *Allorisma subcuneata*, M. and H.; *Aviculopecten occidentalis* (Shum.), M. and W. (?); *Nuculana bellistriata*, Stevens, var. *attenuata*, Meek (?); *Dawsonella meeki*, Bradley (?); *Lophophyllum proliferum* (McChesney), Meek; *Fistulipora nodulifera*, Meek; *Rhombopora lepidodendroides*, Meek; *Archœcidaris*, two forms, and *Phillipsia major*, Shumard (?).

The list of Meek and Hayden contains 16 species and my list 19 additional species, making the total number 35. I think there can be no doubt but that the shales and argillaceous limestones in the upper part of the railroad cut near the foot of Blue mount represent Meek and Hayden's bed called number 37. There are also fossils in the dark gray to bluish limestone near the railroad level which probably represent their number 39.

I am not confident of this horizon in Swallow's section, although I am inclined to think that it is the *Fusulina* shales—number 96—of his upper coal series, which were described as "dark blue marly shale," 12 feet thick, containing "numerous Carboniferous Brachiopoda," exposed at Manhattan, Cottonwood and Mill creek.

### *MOUNT PROSPECT EXPOSURE OF MEEK AND HAYDEN'S BED 34.*

This bed is described as composed of "alternations of bluish, purple and ash-colored calcareous clays, passing at places into clay stones and containing, in a thin bed near the middle, *Spirifer planoconvexa*, *Spirigera subtilita*, *Productus splendens* (?), *Rhynchonella uta*," etcetera,* the base of which, according to their section, is 126½ feet above the Kansas river. On the steep western slope of mount Prospect, about 120 feet (barometrically) above the river, is a bluish shale between two calcareous layers, which contains a great many specimens of two or three species. The list is as follows:

1. *Spirifer* (*Martinia*) *planoconvexus*, Shumard. (*a*)
2. *Rhynchonella uta* (Marcou), Meek. (*c*)
3. *Athyris subtilita* (Hall), Newb. (*c*)

* Proc. Acad. Nat. Sci., Phila., vol. xi, p. 18.

4. *Hustedia mormonii* (Marcou), H. and C. (*rr*)
5. *Productus longispinus,* Sowerby. (*rr*)
6. *Cladodus mortifer,* Newberry and Worthen. (*rr*)
7. *Orthoceras* * sp. (*rr*)

This fossiliferous shale undoubtedly represents bed 34 of Meek and Hayden. Below this horizon and near the base of the quarry on mount Prospect is a yellowish calcareous shale, probably in bed 37 of Meek and Hayden, which contains *Spirifer* (*Martinia*) *planoconvexus,* Shum.; *Productus cora,* d'Orbigny; *Athyris subtilita* (Hall), Newberry, and other species.

### *BASE OF SWALLOW'S PERMIAN.*

*Bed 27 of Meek and Hayden.*—The lowest prominent terrace of the bluffs in the vicinity of Manhattan is composed of the drab, hard limestone which is mentioned as forming the top of number 3 of my section. It is well shown at the northern end of mount Prospect, as well as on Blue mount. This stratum is probably number 27 of Meek and Hayden's section, which is described as a "gray limestone, often fragmentary, with much clay above; lower part hard and more or less cellular in middle," exposed near Ogden Ferry and Manhattan; and, taking into consideration the thickness which they give for the intervening beds, about 58 feet above the *Rhynchonella uta* (Marcou), Meek, zone.†

"*Dry Bone Limestone*" *of Swallow.*—This stratum is an important one in Professor Swallow's section, as it forms the base of the rocks which he called the lower Permian. The beds of this part of his section are well described and may be readily identified in the region about Manhattan. This drab limestone was called the "Dry bone limestone, brown, concretionary and cancellated limestone, 5 feet, *Synocladia biserialis, Spirifer planoconvexa,*" etcetera, at Manhattan and Mill creek. Next above this stratum Swallow gave one foot of bluish brown marls, and then bed number 82:

> "*Cotton rock,* 5 feet; a light cream-colored argillo-magnesian limestone; sometimes in thin beds, with shale partings." ‡

This stratum is well exposed at numerous places near Manhattan, as at the northern end of mount Prospect, along the Manhattan-Ogden road west of Wild Cat creek, etcetera, and is quarried to some extent for

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* This specimen is somewhat similar to figure 5, plate 30, vol. 5, Geol. Surv. of Illinois, which is not identified specifically.

† My barometric section of mount Prospect gave me about 45 feet; but, on account of the rapid changes in the barometer that day, I am not confident of the approximate accuracy of this reading Consequently I am quite willing to admit the thickness of these beds to be greater than 45 feet, although I fancy 58 feet is an overestimate of their actual thickness as shown in the vertical section near the top of mount Prospect.

‡ Prel. Rep. Geol. Survey Kansas, p. 16.

building stone. The layers vary from about 6 inches to 1 foot in thickness. This is probably number 3 of Professor Broadhead's Manhattan section, which he described as a "rather uniformly fine-grained limestone" 3½ feet in thickness,* and it is also Meek and Hayden's bed 26, a light gray, argillaceous limestone showing on weathered surfaces a somewhat laminated structure; contains large spines of *Archæocidaris*,† exposed near Ogden Ferry and Manhattan, and 9 feet in thickness. Professor Swallow stated that these three beds, numbers 82 to 84, "are sometimes represented by a bluish gray and buff, porous magnesian limestone," which is exposed on the Cottonwood. This stratum is well shown on the north side of the Cottonwood river east of Strong City and 3½ miles west of the city or on the south side of the river toward Elmdale. In a paper by Professor Erasmus Haworth and Mr M. Z. Kirk on the Cottonwood River section this limestone stratum was called number 12 of their section.‡

Above the thin limestones are shales and marls, with thin limestone layers, which Swallow described as "blue, brown, purple and green" in color, 31 feet in thickness, while Meek and Hayden assign a thickness of about 36 feet to this bed.

### *THE MANHATTAN STONE.*

*Its Thickness and general Characteristics.*—Capping the shales just referred to is a massive limestone stratum, number 5 of my section, the base of which Professor Swallow gave as 37 feet above the "dry bone" or irregular limestone, Meek and Hayden as 45 feet, and the writer about 40 feet on mount Prospect. This stratum is a massive yellowish to light gray limestone, 5 feet thick, containing a considerable amount of chert and in the upper part large numbers of *Fusulina cylindrica*, Fischer, and is known as the Manhattan stone, being the most important economic as well as stratigraphic horizon in the Manhattan section. The rock, which is very valuable for building and abutment stone, is quarried extensively in the vicinity of Manhattan and forms a well marked stratum, which, when taken in connection with the yellowish, fossiliferous shale on top, is the most distinctive and readily traced formation yet seen in the upper Paleozoic rocks of Kansas. In another unpublished paper I dwell upon this fact in connection with the Cottonwood River section, and here I wish to call attention to the same fact in reference to the Manhattan limestone and shale in order to show that these formations are one and the same.

*Bed 24 of Meek and Hayden.*—The Manhattan limestone is bed 24 of Meek and Hayden's section, which was described as a "hard, very light

* Trans. St. Louis Acad. Science, vol. iv, p. 491.
† Proc. Acad. Nat. Sci., Phila., vol. xi, p. 17.
‡ Kansas Univ. Quarterly, vol. ii, p. 113, and pl. iv, fig. 3.

yellowish gray magnesian limestone, with *Fusulina* and spines of *Archæocidaris*," 6 feet in thickness, and forming a marked horizon about 10 miles below Fort Riley.* The sum of the thickness of all the beds below the Manhattan stone down to the level of the Kansas river at Manhattan according to their section is 242 feet, which, from the position of the limestone on Blue mount and from the determination of its elevation by an exact survey, we know to be overestimated about 40 feet. It is true that Meek and Hayden did not report this stratum at Manhattan, but stated that it formed a marked horizon 10 miles below Fort Riley. The present highway from Manhattan to Fort Riley crosses such a ledge four miles southwest of the city, on the bluff east of Eureka lake, and 10 miles from Fort Riley. This is undoubtedly the horizon noted by Meek and Hayden, and there is no question but that it is the Manhattan stone, for the stratum may be readily traced from the hills about Manhattan to this locality. The Manhattan stone is probably bed number 1 of Broadhead's section at Manhattan, which he gave as 4½ feet thick.†

"*Fusulina Limestone*" *of Swallow*.—This stratum forms bed number 80 of Swallow's section, which he named the *Fusulina* limestone, a "buff, porous and magnesian" limestone 6 feet thick, exposed at Manhattan, Cottonwood Falls and Mill creek. It is important in reference to the locality to observe that Professor Swallow noted the occurrence of this limestone not only in the Kansas valley, but in the Cottonwood valley at Cottonwood Falls.

*Fauna of the Shales above the Manhattan Stone.*—Immediately above the Manhattan stone are yellowish shales containing abundant fossils. From several exposures of these shales about Manhattan, particularly on mount Prospect; in the Uhlrich Brothers' quarry, 2½ miles southwest of Manhattan; and farther west, by the side of the Manhattan and Ogden road, on the hill between Wild Cat creek and Eureka lake, the following species were obtained:

1. *Chonetes granulifera*, Owen. (*aa*)
2. *Athyris subtilita* (Hall), Newb. (*c*)
3. *Productus semireticulatus* (Martin), de Koninck. (*c*)
4. *Derbya crassa* (M. and H.), H. and C. (*c*)
   Also some large forms like *D. keokuk* (Hall), H. and C., and *D. robusta* (Hall), H. and C.
5. *Fusulina cylindrica*, Fischer. (*c*)
6. *Synocladia biserialis*, Swallow. (*c*)
7. *Rhombopora lepidodendroides*, Meek. (*c*)
8. *Archæocidaris*, spines and plates. (*c*)
9. *Straparollus* (*Euomphalus*) *subrugosus*, M. and W. (*r*)

* Proc Acad. Nat. Sci., Phila., vol. xi, p. 17.
† Trans. St. Louis Acad. Sci., vol. iv, pt. iii, p 491.

10. *Aviculopecten maccoyi*, M. and H. (*rr*)
11. *Meekella striato-costata* (Cox), White and St. John. (*c*)
12. *Chætetes* cf. *carbonarius*, Worthen. (*c*)
13. *Fistulipora nodulifera*, Meek. (*r*)
14. *Crania* sp. (*rr*)
15. *Crinoid*, segments of stem and plates. (*c*)

*Fauna of the Cottonwood Shale.*—The shale referred to above is very similar in lithologic appearance to the yellowish shale overlying the Cottonwood limestone in the Cottonwood valley, which I have called the "Cottonwood shale." The Cottonwood shale is abundantly fossiliferous, and the following species have been found in the vicinity of Cottonwood Falls and Strong City:

* 1. *Chonetes granulifera*, Owen. (*aa*)
* 2. *Derbya crassa* (M. and H.), Hall and Clarke. (*aa*)
* 3. *Athyris subtilita* (Hall), Newb. (*a*)
* 4. *Productus semireticulatus* (Martin), de Koninck. (*a*)
* 5. *Meekella striato-costata* (Cox), White and St. John. (*c*)
6. *Productus nebrascensis*, Owen. (*r*)
* 7. *Aviculopecten maccoyi*, M. and H. (*r*)
* 8. *Straparollus* (*Euomphalus*) *subrugosus*, Meek and Worthen. (*rr*)
* 9. *Synocladia biserialis*, Swallow. (*rr*)
*10. *Rhombopora lepidodendroides*, Meek. (*rr*)
11. *Lophophyllum proliferum*, McChesney. (*rr*)
*12. *Fusulina cylindrica*, Fischer. (*r*)
13. *Aviculopecten occidentalis* (Shum.), M. and W. (*rr*)
14. *Terebratula bovidens*, Morton. (*rr*)
*15. *Chætetes* sp.
*16. *Crinoid*, segment of stem and plates.
*17. *Archæocidaris*, plates and spines.
18. *Phillipsia scitula*, M. and W. (?). (*rr*)
19. *Glauconome* sp. (*r*)

From the above list it will be seen that all the abundant and really characteristic species are common to the yellowish shales, both of Cottonwood Falls and Manhattan. As far as the present collections are concerned, *Productus nebrascensis*, Owen; *Lophophyllum proliferum*, McChesney; *Aviculopecten occidentalis* (Shum.) M. and W.; *Terebratula bovidens*, Morton; *Phillipsia scitula*, M. and W. (?); and *Glauconome* sp. have been found only in the Cottonwood shale near Cottonwood Falls, and *Crania* sp. only at Manhattan. Undoubtedly careful search would increase the number of species at each locality and probably show a larger number common to both regions. Manhattan is 65 miles north of Cottonwood Falls, and there are as many identical species from two localities belong-

* indicates that the species is common to the Manhattan and Cottonwood shales.

ing to the same formation as could be expected when we take into consideration the distance between them.

Meek and Hayden reported some of the fossils of this shale from the "bluish, light gray and brown clays, with occasional layers of magnesian limestone," which they described as 35 feet thick on top of the Manhattan stone and exposed at the same locality 10 miles below Fort Riley. They mentioned *Chonetes mucronata*, *Orthisina umbraculum* (?) [probably specimens of *Derbya*], *Monotis*, *Fusulina*, etcetera.*

Swallow gives 38 feet of "blue, brown and purple marls, some very much cancellated, and a few beds of thin limestone" exposed on Cottonwood and Clarke's creek, in which are "*Chonetes*, *Productus costatoides*, *Orthisina missouriensis* [*Meekella striato-costata*] and *umbraculum* (?), *Synocladia*, *Archæocidaris* and *Euomphalus*." †

*Correlation of the Manhattan with the Cottonwood Stone.*—Neither Meek and Hayden nor Swallow called attention to the marked stratigraphic and paleontologic characteristics of the Manhattan stone and shale, which are the same for the Cottonwood limestone and shale in the Cottonwood valley. I have described the importance of this horizon in the Cottonwood valley and proposed the name *Cottonwood formation* for the limestone and overlying fossiliferous shales. There seems no question but that the same formation (Cottonwood) is represented by the Manhattan stone and shales, to which, therefore, the same name should be applied.‡

As far as observed, this is the most distinctly marked formation in the upper Paleozoic rocks of Kansas, and probably defines a horizon which may be readily traced across the state, and will be of great assistance in dividing this series of rocks for the purpose of mapping.

Near the summit of hills or where there is a gentle slope the shale is often eroded and the massive limestone simply remains, but usually a little careful search will reveal the yellowish, fossiliferous shale in some run or cut with specimens of *Chonetes granulifera*, Owen; *Athyris subtilita* (Hall), Newb.; *Productus semireticulatus* (Martin), de Koninck, etcetera. Locally this limestone has been known for a long time as the Manhattan limestone,§ and if we bear in mind the fact that it belongs in the Cottonwood formation, this name may be used for that region.

* Proc. Acad. Nat. Sci., Phila., vol. xi, p. 17.

† Prelim. Rept. Geol. Surv. Kansas, pp. 15, 16.

‡ Since the preceding part of this paper was written I have traced the Cottonwood formation (the limestone and shale) across the country from Cottonwood Falls to Manhattan. The formation reaches the Neosho valley near Dunlap, follows the river toward Council Grove, from there extends northeasterly across the high ground near Bushong and Eskridge to the Mill creek valley above Alma, and then northwesterly to Manhattan.

§ Since the above was written Mr Charles D. Walcott has informed me that Manhattan could not be used as a name of a formation, since it is preoccupied by the "Manhattan gneiss" near New York city.

*Dip of the Manhattan Stone.*—The Manhattan stone may be easily traced from Manhattan up the Kansas river to Seven-mile creek, where there is a good exposure on the creek bank by the highway just east of Ogden, with the yellow fossiliferous shale on top. Another exposure occurs a short distance east of the Manhattan and Ogden highway, near the Union Pacific railroad, 15 feet higher than the track. This locality is nine miles southwest of Blue mount, at Manhattan, and there is an approximate difference of 110 feet in the altitude of the Manhattan stone, which gives a dip of 12 feet to the mile.*

Meek and Hayden found the dip of a higher stratum extending from the vicinity of Ogden to Chapman's creek, 23 miles southwest, to be a little less than 14 feet to the mile.†

The greatest dip is supposed to be to the northwest, and the Manhattan stone traced in that direction along the Chicago and Rock Island railroad up Wildcat creek would probably give a greater dip, possibly 20 feet to the mile, as suggested by Meek and Hayden.

## The Mill Creek geologic Section.

### *BUFFALO MOUND SECTION AND FAUNA.*

Professor Swallow, as well as Meek and Hayden, frequently referred to the exposures of rocks along Mill creek, a tributary of the Kansas river southeast of Manhattan. The rocks for a considerable distance below the Manhattan stone, and above it extending into the "flint series," are well exposed in bluffs along the creek. On the south side of the creek, three miles southwest of Maple Hill, is a prominent hill called Buffalo mound. The top of the hill is between 350 and 360 feet above the level of Mill creek. Meek and Hayden gave a detailed section of the mound.‡ At present it is not possible to clearly determine all the beds described by Meek and Hayden in the lower part of the section, although the most important strata are fairly well defined. About 160 feet below the top of the mound is a ledge of bluish gray limestone, which is exposed on the road southeast of the mound and forms a conspicuous ledge for some distance on both sides of the road. This stratum is quite fossiliferous and is probably bed number 2 of Meek and Hayden's section, although it may belong in the lower part of their bed number 1. The following species were collected from the exposure on the highway:

* Gannett (Bull. U. S. Geol. Surv., No. 76) gives the elevation of Manhattan as 1,014 feet. The Manhattan stone on Blue mount is approximately 173 feet above the railroad level, or 1,187 feet above tide. Ogden is given as 1,062 feet, making the approximate elevation of the Manhattan stone 1,077 feet above tide, which would give a difference of 110 feet in the elevation of the Manhattan stone at the two localities.

† Proc. Acad. Nat. Sci., Phila., vol. xi, p. 22.

‡ Ibid., pp. 12, 13.

1. *Productus longispinus*, Sowb. (*a*)
2. *Productus semireticulatus* (Martin), de Koninck. (*rr*)
3. *Athyris subtilita* (Hall), Newb. (*r*)
4. *Rhynchonella uta* (Marcou), Meek. (*r*)
5. *Spirifer* (*Martinia*) *planoconvexus*, Shum. (*rr*)
6. *Chonetes granulifera*, Owen. (*rr*)
7. *Derbya crassa* (M. and H.), H. and C. (?). (*rr*)
8. *Meekella striato-costata* (Cox), White and St. John. (*rr*)
9. *Spirifer cameratus*, Morton. (*rr*)
10. *Chonetes verneuiliana*, N. and P. (*rr*)
11. *Pinna peracuta*, Shum. (*rr*)
12. *Allorisma geinitzii*, Meek (?). (*rr*)
13. *Phillipsia scitula*, M. and W. (?). (*rr*)
    Simply a fragment of the buckler.
14. *Campophyllum torquium* (Owen), Meek (?). (*rr*)
15. *Fusulina cylindrica*, Fischer.
    Abundant in the shaly limestone on top of the massive stratum, but also in the massive rock.
16. *Crinoid* stems. (*r*)

### *McFARLAND SECTION AND COMAPRISON OF ITS FAUNA WITH THAT OF BUFFALO MOUND.*

The bluff on the south bank of Mill creek, opposite the railroad station at McFarland, nine miles west of Buffalo mound, affords a good section. The following beds are exposed in descending order:

| | Feet | Feet |
|---|---|---|
| 10. Yellowish, somewhat porous rock, capped by gray shaly limestones to the summit of the bluff. | | |
| 9. Light gray shaly limestone near the top of bluff, containing *Pseudomonotis hawni* (M. and H.) and *Aviculopecten occidentalis* (Shum.), M. and H. | 1 = | 155 |
| 8. Slope mostly covered; few exposures.......... 7. Shaly light gray limestone, with *Fusulina*.......... | 71 = | 154 |
| 6. Slope covered.......... | 31 = | 83 |
| 5. Bluish gray massive limestone, containing fossils.......... | 1 = | 52 |
| 4. Slope mostly covered.......... | 42 = | 51 |
| 3. Greenish, blue and yellowish shale, alternating with light gray and yellowish limestone, containing plenty of fossils. | 7 = | 9 |
| 2. Coal, 3 inches in thickness. | | |
| 1. Blue shale, reaching the level of Mill creek.......... | 2 = | 2 |

The lower part of number 3 contains numerous fossils, and the following species were obtained:

1. *Chonetes granulifera*, Owen. (*aa*)
2. *Chonetes glabra*, Geinitz. (*rr*)
3. *Productus longispinus*, Sowb. (*c*)
4. *Productus semireticulatus* (Martin), de Koninck. (*c*)

5. *Productus cora*, d'Orbigny. (*c*)
   Part of the specimens are larger than the ordinary specimens of this species and possibly belong to the *P. æquicostatus* of Shumard;* but Dr White states † that *P. cora* sometimes reaches a large size.
6. *Spirifer* (*Martinia*) *planoconvexus*, Shum. (*c*)
7. *Productus nebrascensis*, Owen. (*r*)
8. *Productus symmetricus*, McChesney. (*rr*)
9. *Spiriferina kentuckensis*, Shum. (*rr*)
10. *Hustedia mormonii* (Marcou), H. and C. (*r*)
11. *Meekella striato-costata* (Cox), White and St. John. (*rr*)
12. *Syntrilasma hemiplicata* (Hall), M. and W. (*rr*)
13. *Spirifer cameratus*, Morton. (*rr*)
14. *Terebratula bovidens*, Morton. (*rr*)
15. *Derbya crassa* (M. and H.), H. and C. (*rr*)
16. *Phillipsia scitula*, Meek and Worthen. (*rr*)
17. *Synocladia biserialis*, Swallow. (*r*)
18. *Rhombopora lepidodendroides*, Meek. (*r*)
19. *Chætetes* sp. (*rr*)
20. *Crinoid*, stems and plates. (*r*)
21. *Fusulina cylindrica*, Fischer. (*c*)

From the second limestone—stratum number 5 of the section—Mr Warren Finney, who assisted me in the work on Mill creek, obtained the following species:

1. *Productus longispinus*, Sowb. (*a*)
2. *Spirifer* (*Martinia*) *planoconvexus*, Shum. (*c*)
3. *Hustedia mormonii* (Marcon), H. and C. (*r*)
4. *Athyris subtilita* (Hall), Newb. (*r*)
5. *Spirifer cameratus*, Morton. (*r*)
6. *Rhynchonella uta* (Marcou), Meek. (*r*)
7. *Derbya crassa* (M. and H.), H. and C. (?). (*r*)
   Not clearly preserved.
8. *Chonetes granulifera*, Owen. (*rr*)
9. *Productus nebrascensis*, Owen (?). (*rr*)
10. *Productus cora*, d'Orbigny (?). (*rr*)
11. *Spiriferina kentuckensis*, Shum. (*rr*)
12. *Discina nitida* (Phillips), Meek and Worthen. (*rr*)
13. *Meekella striato-costata* (Cox), White and St. John. (*rr*)
14. *Pinna peracuta*, Shum. (*r*)
15. *Myalina subquadrata*, Shum. (*rr*)
16. *Allorisma subcuneata*, M. and H. (*rr*)
17. *Aviculopecten occidentalis* (Shum.), Meek and Worthen. (*rr*)
18. *Straparollus* (*Euomphalus*) *subrugosus*, Meek and Worth. (*rr*)
19. *Phillipsia scitula*, Meek and Worthen. (*r*)
20. *Fusulina cylindrica*, Fischer. (*c*)

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* Geol. Surv. Mo., 1855, part 2, p. 201.
† Thirteenth Report Indiana Geol. Survey, p. 126.

It seems probable that the above stratum is the same as the bluish gray, fossiliferous limestone described on Buffalo mound, although the stratum has not yet been carefully traced from the mound to McFarland.

### *ALMA SECTION.*

*Its Thickness and Fauna.*—At Alma, 4 miles southwest of McFarland and 18 miles southeast of Manhattan, on the east bank of Mill creek, is a section of the same rocks as those exposed in the bluffs of the Kansas river near Manhattan. The following section refers to that part of the bluff on which is the quarry of the "Sunflower cement works," capped by an exposure of the Alma massive limestone:

| | Inches. | Feet. |
|---|---|---|
| 12. Thin limestone but a few inches beneath the soil.......... ..... | 6 | =181 |
| | Feet. | Feet. |
| 11. Yellowish shale, with concretions in the upper part and abundant fossils in the lower portion. | 10 | =180½ |
| 10. Light yellowish gray, massive limestone, locally called the "Alma stone." | 5½ | =170½ |
| 9. Covered slope.............................................. .......... | 40 | =165 |
| 8. Argillaceous, thin bedded limestone, with a hard, irregular limestone at the base. | 10 | =125 |
| 7. Slope showing outcrops of shaly limestone and shales, but mainly covered. In the shaly limestone or calcareous shales are specimens of *Fusulina cylindrica*, Fischer. | 18 | =115 |
| 6. Massive grayish limestone at top of cement quarry ............. | 2 | = 97 |
| 5. Olive shale.................................................. | 7 | = 95 |
| 4. Drab limestones, with one layer of drab shale. The limestones are used for cement and known as numbers 1 to 3 of the cement quarry. | 5½ | = 88 |
| 3. Yellowish, very friable chalk-like limestone, number 4 of the cement quarry. | 5 | = 82½ |
| 2. Bluish and yellowish white shale, the lower containing concretions | 7½ | = 77½ |
| 1. Covered slope to Mill creek ..................................... | 70 | = 70 |

From the lower part of the yellow shales, number 11 of the section, the following species were obtained:

1. *Chonetes granulifera*, Owen. (*aa*)
2. *Athyris subtilita* (Hall) Newb. (*a*)
3. *Productus semireticulatus* (Martin) de Koninck. (*c*)
4. *Meekella striato-costata* (Cox) White and St. John. (*rr*)
5. *Derbya crassa* (M. and H.) H. and C. (?). (*rr*)
6. *Rhombopora lepidodendroides*, Meek. (*rr*)
7. *Fusulina cylindrica*, Fischer. (*rr*)
8. *Archæocidaris* sp. (*c*)
9. *Crinoid* stems. (*rr*)

*Correlation of the Alma with the Manhattan Stone.*—The massive limestone (number 10) below the yellowish shales, called the Alma stone, is

quarried to a considerable extent near Alma, and is simply another exposure of the Manhattan or Cottonwood limestone. Therefore the massive limestone, with the overlying yellow, fossiliferous shale, near Alma represents the rocks which I have called the Cottonwood formation.

Professor Swallow mentioned the occurrence on Mill creek * of his *Fusulina* limestone, number 80 of his section (which we have shown is the Manhattan and Cottonwood limestone); his "Cotton rock," number 82 (the argillaceous limestones at the top of our number 8), and his "Dry bone limestone," number 84 (the hard irregular limestone which with the overlying argillaceous limestones we have called number 8 of the Alma section).

This lower limestone Professor Swallow called the base of the Permian, and he stated that there was an unconformity on Mill creek, where this "Dry bone limestone" (number 84) rests on what he called the "*Fusulina* shales" (number 96), while beds numbers 85 to 95, which represent strata 86 feet in thickness exposed at Manhattan, are missing on Mill creek.†

*First Flint Bed above the Alma Stone.*—Near the top of the high hill east of the Cement and Alma stone quarries, and two miles east of Alma, is another limestone quarry. The stratum is not so massive as that of the Alma stone, and above it is a shale which is capped by layers of limestone alternating with chert and covered by a few inches of soil. This chert or flint bed is barometrically about 145 feet above the top of the Alma stone, or between 310 and 315 feet above the level of Mill creek. On the summit is an excavation in which the alternating layers of gray limestone and chert are nicely shown. This shaly limestone is somewhat fossiliferous. A few fossils were also found in the chert, and the following species were obtained at this locality:

1. *Syntrilasma hemiplicata* (Hall), Meek and Worthen. (*c*)
2. *Athyris subtilita* (Hall), Newb. (*c*)
3. *Chonetes granulifera*, Owen. (*rr*)
4. *Derbya crassa* (M. and H.), H. and C. (?) (*rr*)
5. *Productus nebrascensis*, Owen. (*rr*)
6. *Pseudomonotis hawni* (M. and H.). (*rr*)
7. *Bryozoan* sp. (*rr*)

## THE GEOLOGIC SECTION OF THE UPPER KANSAS RIVER.

### *GENERAL CHARACTERISTICS.*

Above the Manhattan stone on the Kansas river is a series of blue, drab and chocolate colored shales alternating with thin buff, drab and

* Prelim. Rept. Geol. Surv. Kansas, p. 16.

† Ibid., p. 44; also, see Trans. Acad. Science, St. Louis, vol. ii, 1868, p. 521.

bluish limestones. A part of these shales and limestones are quite fossiliferous, although less strikingly so than the yellowish shale immediately on top of the Manhattan stone.

### *LAMELLIBRANCH FAUNA ABOVE THE MANHATTAN STONE.*

About 45 feet above the top of the Manhattan stone is a shaly, fossiliferous limestone which contains numerous specimens of lamellibranchs; above it are usually some 20 feet of bluish and chocolate shales succeeded by a limestone containing lamellibranchs; then about 10 feet of bluish and yellowish shales or shaly limestone capped by another thin, fossiliferous limestone. This series of shales and limestones containing the lamellibranch fauna is about 36 feet in thickness and is apparently continuous and characteristic of this horizon. The lowest shaly limestone is probably bed 76 of Swallow's section, which he characterized as a "soft blue and gray coraline limestone, 3 feet" on Cottonwood and Clarks creek.* In Swallow's section this bed is given as 49 feet above the top of the Manhattan stone and the following fossils are mentioned:

"*Monotis halli* and *americana* [Swallow had stated that this species was the *Monotis hawni* of Meek and Hayden (Trans. Acad. Sci. St. Louis, vol. i, no. 2, 1858, p. 186, foot-note), which later was changed generically to *Pseudomonotis*], *Productus norwoodi*, *Synocladia biserialis*, *Thamniscus dubius* (?), *Edmondia hardni*, *Phillipsia cliftonensis*," etcetera.

The higher limestones of this horizon are probably respectively number 68 of Swallow, which was described as a "hard blue and buff magnesian limestone, containing numerous Permian *Acephala*," and number 66, a "light buff and drab argillo, magnesian limestone," containing "*Monotis* and *Bakevellia*."† This fauna was noticed by the writer at numerous localities in the Cottonwood valley, and the largest collection of fossils was obtained at Matfield Green, where there is a good exposure on the bank of the South fork of Cottonwood river. The following species were obtained:

1. *Pleurophorus subcostatus*, Meek and Worthen. (*a*)
2. *Productus nebrascensis*, Owen. (*a*)
3. *Aviculopecten occidentalis* (Shum.), Meek and Worthen. (*a*)
4. *Pseudomonotis hawni*, M. and H. (*c*)
5. *Pseudomonotis hawni* (M. and H.), var. *ovata*, M. and H. (*c*)
6. *Bellerophon* cf. *sublævis*, Hall, or *carbonarius*, Cox. (*a*)
7. Small *Gasteropod* cf. *Aclis* sp. (*c*)
8. *Myalina* (?) *swallovi*, McChesney. (*c*)
9. *Edmondia* cf. *nebrascensis* (Geinitz), Meek. (*r*)

* Prelim. Rept. Geol. Surv. Kansas, p. 15. The Clarks creek mentioned frequently in Swallow's section is supposed to be the creek entering the Kansas river from the south nearly opposite the eastern line of the Fort Riley Military Reservation.

† Op. cit., p. 15.

10. *Myalina kansasensis*, Shum. (*rr*)
11. *Myalina perattenuata*, M. and H. (*rr*)
12. *Pinna peracuta*, Shum. (*rr*)
13. *Bellerophon* cf. *montfortianus*, N. and P. (*rr*)
14. *Allorisma* cf. *subcuneata*, M. and H. (*rr*)
15. *Schizodus* cf. *curtiforme*, Walcott. (*rr*)
16. *Macrochilina angulifera*, White (?). (*r*)

### *FIRST FLINT BED ABOVE THE MANHATTAN STONE.*

*Its Character and Position.*—The next prominent stratum above the Manhattan stone is a limestone containing an abundance of chert, which is crossed by the road near the brow of the hill on the east side of Seven-mile creek about 1½ miles north of the exposure of Manhattan stone. The barometer made this ledge 122 feet higher than the top of the Manhattan limestone, and it is the lowest of the so-called "flint ledges."

*Bed 18 of Meek and Hayden.*—This stratum is bed 18 of Meek and Hayden's section, which was described as—

"A light gray and whitish magnesian limestone, containing *Spirigera, Orthisina umbraculum* (?), *O. shumardiana, Productus calhounianus, Acanthocladia americana* and undetermined species *Cyathocrinus.* Lower part containing many concretions of flint. Fort Riley and on Cottonwood creek." *

The sum of the several beds between the base of this "flint ledge" and the top of the Manhattan stone is 109 feet, as reported by Meek and Hayden.

"*Fifth cherty Limestone*" *of Swallow.*—The same stratum forms bed number 62 of Swallow's section, which is called the "fifth cherty limestone," and described as "a light drab and buff cherty magnesian limestone, 12 feet," containing *Productus calhounianus, Chonetes mucronata, Orthisina* like *umbraculum, Athyris* like *subtilita,* and *Crinoids,* exposed near Fort Riley.†

According to Swallow's section, the beds between the Manhatten stone and the "fifth cherty limestone" vary in thickness from 124 to 153 feet. This "flint bed" forms the top of the steep bluff one-half mile west of Ogden, at the eastern line of the Fort Riley Military Reservation, where according to the barometer, it is 105 feet above the highway, which is near railroad level. The ledge is plainly exposed along the bluff to the west, and after crossing Three-mile creek it shows near the summit of the sharp point west of the creek and about 50 feet above the highway.

"*Wreford Limestone*" *of Hay.*—This cherty ledge occurs in the lower part of the Fort Riley section, which recently has been well described by

* Proc. Acad. Nat. Sci., Phila., vol. xi, p. 17.
† Prelim. Rept. Geol. Surv. Kansas, p. 14.

Professor Robert Hay,* and thus the relation of the Manhattan section to the one at Fort Riley is shown.† This flint bed forms number 5 of Professor Hay's section at Fort Riley, 40 feet above the base of the section which he called "the lower flint beds" and for which the name "Wreford limestone" was proposed. The Professor stated that the bed was worked for lime at Wreford, south of Junction City, and also noted its occurrence near the top of the bluffs at the eastern edge of the Fort Riley Military Reservation. This is the locality mentioned above, and if for any reason the local name of Wreford limestone should not prove desirable, on account of the prominence of this ledge near Ogden, it might appropriately be called the Ogden flint.

### *FORT RILEY SECTION.*

*Professor Hay's Investigations.*—Professor Hay has prepared a geologic map and report upon the Fort Riley Military Reservation, now passing through the press, which will give the local particulars of the Fort Riley and Junction City region; consequently we will only mention the most important geologic characters of this region, and refer the reader to Professor Hay's paper for a detailed account. It is interesting to observe the points of agreement between these several sections, the more noticeable of which we will briefly mention.

*Second Flint Bed and its Correlatives.*—A higher flint bed, forming number 9 of Hay's section, is composed of limestones containing numerous flint nodules, separated by layers of flint. In the Fort Riley section, from the base of number 5 (Wreford limestone) to the base of number 9 is 77 feet, according to Professor Hay's section. This upper flint is bed 14 of Meek and Hayden, and from its base to the base of the lower flint (number 18) is 107 feet. Swallow noted the same stratum, which is bed 54 of his section, or what he called the "third cherty limestone," and he gives the thickness of the beds corresponding to that given in the two preceding sections as varying from 85 to 131 feet.

*Fort Riley Limestone and its Correlatives.*—Near the summit of the hills about Fort Riley is a conspicuous stratum, number 11 of Professor Hay's section, which he called "the Fort Riley main ledge, a buff magnesian limestone," 6 feet in thickness, and on this rests number 12, "buff limestones with shale partings, changing to shales with limestone ledges" from 30 to 40 feet thick.

* Seventh Bien. Report Kansas State Board Agri., vol. xii, 1891, part I, p. 94. Eighth ibid., vol. xiii, 1893, part II, p. 104.

† Professor Hay, in his table of "the rocks of Kansas," used the term "Manhattan beds," but stated that "what I have called Manhattan beds in the geological scheme I have not had the opportunity to work out in detail" (Eighth Bien. Report, pp. 101, 104).

Meek and Hayden accurately noted these beds—number 12 of their section representing number 11 of Hay's—which they described as "a light grayish yellow, rather granular, magnesian limestone;" mentioned several fossils, and stated that it "forms a distinct horizon near summit of hills in vicinity of Fort Riley; also seen on Cottonwood creek."* Number 11 of Meek and Hayden represents number 12 of Hay, which they described as a "light grayish and yellow magnesian limestone in layers and beds, sometimes alternating with bluish and other colored clays," containing *Pleurophorus subcuneata*, *Bakevellia parva*, *Euomphalus* near *rugosus*, *Spirigera* [*Athyris*], allied to *subtilita*, but more gibbous; *Orthisina umbraculum?*, *O. shumardiana* and others, while the locality was given as the "summit of the hills near Fort Riley and above there; also seen on Cottonwood creek" from 25 to 35 feet in thickness. Certain layers of this bed contain abundant specimens of *Bakevellia parva*, M. and H., and *Pleurophorus subcuneatus*, M. and H., while *Aviculopecten occidentalis* (Shumard), Meek and Worthen, *Euomphalus* sp. and other species are rare. Number 11 of Hay's section is number 52 of Swallow's, which Swallow called the "Fort Riley limestone," a name that seems very appropriate for this horizon, and he characterized it as "a buff, porous magnesian rock in thick beds," containing *Productus calhounianus*, *Orthisina shumardiana*, *Archæocidaris*, *Bakevellia*, etcetera, 8 to 10 feet thick, and exposed near Fort Riley, Cottonwood and Fancy creek.† The limestones and shales called number 12 by Hay and number 11 by Meek and Hayden were subdivided by Swallow into a number of beds.

## Review of the geologic Correlation of the Kansas River Section.

The geologic correlation of the beds composing the Fort Riley section is a very interesting question, which, considering the length of the present paper, cannot now be taken up for general review, but which the writer hopes to attempt at another time, together with the comparison of this upper part of the Kansas section with the upper Cottonwood section. In closing it might be noted that Professor Hay divided the section into the upper and lower Fort Riley beds, number 11 (the Fort Riley limestone) forming the base of the upper beds. The Professor

* Proc. Acad. Nat. Sci., Phila., vol. xi, p. 17.

‡ Prelim. Rept. Geol. Surv. Kansas., p. 14.

During the past summer, in connection with the preparation of the geologic maps of the Cottonwood Falls and Parkerville sheets, I determined that the "Fort Riley limestone" is the same limestone as the one worked in the quarries near Florence in the Cottonwood valley. This limestone may be followed, especially on the south side, for some distance along the bluffs of the Cottonwood river.—C. S. P., November 17, 1894.

called these upper beds (beginning at the bottom of number 11) Permian, as he states—

"on the authority of the Russian geologist, Professor Tschernyschew, who visited the neighborhood of Fort Riley in the summer of 1891 in company with H. S. Williams, of Cornell University, and who recognized these beds as similar to typical beds in his own country, whence—in the province of Perm—they had their name." *

The lower Fort Riley and Manhattan beds constitute the Permo-Carboniferous rocks of Professor Hay's classification.†

Meek and Hayden drew the line between the Permo-Carboniferous and the Permian at the top of their number 11 (the bed of thin limestones above the Fort Riley limestone) and called number 10 and the higher beds Permian. This line was based on paleontologic grounds, and was drawn rather as an attempt to conform to the European classification than to represent any decided lithologic or paleontologic change, for it is stated that—

"The passage from the Carboniferous to the strata containing Permian types is so gradual here that it seems to us no one undertaking to classify these rocks, without any knowledge of the classification adopted in the old world, would have separated them into distinct *systems*, either upon lithological or paleontological grounds." ‡

These bluish, light gray and red laminated shales, with thin beds of yellowish magnesian limestone (number 10 of Meek and Hayden), according to Meek and Hayden, contain *Monotis* [*Pseudomonotis*] *hawni*, *Myalina perattenuata*, *Pleurophorus* (?) *subcuneata*, *Edmondia* (?) *calhouni*, *Spirigera* [*Athyris*] near *subtilita*, *Nautilus eccentricus*, *Bakevellia parva*, *Leda subscitula*, *Axinus rotundatus* and other species, while the rocks occur "near Smoky Hill river on high country south of Fort Riley, as well as on Cottonwood creek," and are 90 feet thick.§ A "second edition of a geological map of Nebraska and Kansas," published by Dr Hayden in 1858, represents the Permian system in northern and central Kansas, the lower line of which crossed the Republican and Smoky Hill rivers some distance west of Fort Riley.|| All the beds exposed along the Kansas

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* Eighth Bien. Report Kansas State Board Agriculture, part ii, p. 104, and see "the rocks of Kansas" on p. 101.

In Trans. Kans. Acad. Sci., vol. xiii, 1893, p. 38, Professor Hay says that Professors Tschernyschew and H. S. Williams "have made a short examination of the section exposed at Fort Riley, and, while agreeing that the lower beds are Permo-Carboniferous, they state that the upper beds . . . are decidedly Permian, the Russian professor assuring me that both faunal and lithologic characters can be duplicated in the Permian of his own country."

† Eighth Bien. Report, part ii, p. 101.

‡ Proc. Acad. Nat. Sci., Phila., vol. xi, p. 20.

§ Op. cit., p. 16.

|| Proc. Acad. Nat. Sci., Philadelphia, June, 1859. On p. 144, foot-note, it is stated that the Permian formation in Kansas is represented on the map "from information derived from Major Hawn's explorations."

river, from number 84 at Manhattan to the highest in the vicinity of Fort Riley, belong to Swallow's Lower Permian. Swallow made the base of his Upper Permian, bed number 30, which, according to his section, is exposed on Fancy (Riley county) and Turkey (Dickinson county) creeks and the Cottonwood, and is from 126 to 176 feet above the top of the Fort Riley limestone.

Dr Hayden reviewed Swallow's "Preliminary Report of the Geological Survey of Kansas"* and restated the reasons for Meek and Hayden's division of the upper Paleozoic rocks of Kansas. Dr Hayden said:

"As we ascend in the series we find that after going some distance above the supposed line of demarkation [Swallow's] the Carboniferous species gradually begin to disappear and the Permian types become rather more common in particular beds until we have ascended to a point near the horizon Professor Swallow makes the line between the Upper and Lower Permian, when we find we have almost completely lost sight of the familiar Carboniferous species, a few of which had continued on up to near this point, and see scarcely any but forms such as in Europe would be regarded as Permian types. There is no physical break here, however, nor *abrupt* change of fossils; hence Meek and Hayden regarded the beds below the horizon, down so far as to include most, if not nearly all, of Professor Swallow's Lower Permian, as an intermediate connecting series between the Permian and Coal Measures, which, if worthy of a distinct name at all from the latter, should be called Permo-Carboniferous, while the beds above they regarded alone as properly the equivalent of the true Permian of Europe." †

Professor Swallow prepared a paper‡ answering Dr Hayden, in which he said in reference to the rocks called Permo-Carboniferous by Meek and Hayden:

"My principal reason for calling these rocks Permian is that they contain many more Permian than Carboniferous fossils, while Messrs Meek and Hayden declare the preponderance is in favor of Carboniferous fossils." §

As stated by Dr H. S. Williams in his chapter on "The Permian problem of Kansas and Nebraska:"

"Professor Swallow's article is controversial and adds little to the settlement of the problem, but brings out clearly the attitudes of the disputants." ||

## Chart of Sections.

On the following chart I have tabulated the beds composing the sections of Meek and Hayden, Swallow, and Hay, and indicated the general correlation of the sections as described by these geologists.

* Am. Jour. Science, 2d series, vol. 44, July, 1867, pp. 32–40. Dr. Hayden says on p. 32: "Mr. Meek has furnished some carefully prepared notes which form the substance of this article."

† Ibid., p. 37.

‡ Trans. Acad. Sci. St. Louis, vol. ii. April, 1868, pp. 507–526.

§ Ibid., p. 516.

|| Bull. U. S. Geol. Survey, No. 80, p. 206.

*Chart giving tabulated Sections* of the Rocks exposed along the Kansas River southwest of Manhattan, as described by Meek and Hayden, Swallow,† and Hay.*

**Meek and Hayden's Section.**

| | Bed. | Feet. | Feet. |
|---|---|---|---|
| Permian. | | | 627 |
| Permian. | No. 10. Bluish, gray and red laminated shales, alternating with yellowish magnesian limestone containing fossils. | 90 | |
| | | | 537 |
| Permo-Carboniferous. | No. 11. Light gray and yellow magnesian limestone in layers, alternating with shales, quite fossiliferous. | 25–35 | |
| | | | 512 |
| Permo-Carboniferous. | No. 12. Light grayish yellow magnesian limestone, with some fossils. | 7–8 | |
| | | | 505 |
| Permo-Carboniferous. | No. 13. Soft argillo-calcareous bed. | 5 | |
| | | | 500 |
| Permo-Carboniferous. | No. 14. Light grayish and yellowish magnesian limestone, with fossils and containing many concretions of flint. | 38 | |
| | | | 462 |
| Permo-Carboniferous. | No. 15. Bluish, yellowish and brown shales. | 35 | |
| | | | 427 |
| Permo-Carboniferous. | No. 16. Yellowish magnesian limestone, with fossils. | 4 | |
| | | | 423 |
| Permo-Carboniferous. | No. 17. Blue, red and light gray shales. | 28 | |
| | | | 395 |
| Permo-Carboniferous. | No 18. Light gray magnesian limestone, with fossils, lower part containing many flint concretions. | 40 | |

**Swallow's Section.** (Permian.)

| Feet. | Feet. | Bed. |
|---|---|---|
| | ‡ | *Top of Lower Permian.* |
| 640 | | |
| | 40 | Various colored shales, alternating with limestones containing fossils. |
| 600 | | |
| | 4 | No. 40. First cherty limestone. |
| 596 | | |
| | 16 | Shales and magnesian limestones. |
| 580 | | |
| | 4 | Second cherty limestone, containing much chert. |
| 576 | | |
| | 64 | Various colored shales, alternating with magnesian limestones. |
| 512 | | |
| | 8–10 | No. 52. Fort Riley limestone—buff magnesian rock, with fossils. |
| 504 | | |
| | 6 | No. 53. Blue and brown shales. |
| 498 | | |
| | 40 | Third cherty limestone—light buff and magnesian, with fossils. |
| 458 | | |
| | 49 | Shales and limestones. |
| 409 | | |
| | 10–24 | Fourth cherty limestone. |
| 399 | | |
| | 14 | Blue, drab and brown shales. |
| 385 | | |
| | 12 | Fifth cherty limestone, with fossils. |
| 373 | | |
| | 11–23 | No. 63. Shales with fossils. |
| 362 | | |
| | 19 | Shales and limestones. |
| 343 | | |
| | 15 18 | No. 66. Magnesian limestone, with *Monotis.* |

**Hay's Section.**

| Feet. | Feet. | Bed. | |
|---|---|---|---|
| 213 | | | |
| | 10 | No. 14. Impure limestones, with some flints. | Permian. |
| 203 | | | |
| | 50–60 | No. 13. Light colored shales, with lavender flags containing some fossils. | Permian. |
| 153 | | | |
| | 30–40 | No. 12. Buff limestones, with shale partings and quite fossiliferous. | Permian. |
| 123 | | | |
| | 6 | No. 11. The Fort Riley main ledge—a buff magnesian limestone. | Permian. |
| 117 | | | |
| | 15 | Light colored shales. | |
| 102 | | | |
| | 25–30 | No. 9. Upper flint beds—limestones separated by layers of flint. | |
| 77 | | | |
| | 30 | Shales of various colors. | |
| 47 | | | |
| | 6 | No. 7. Limestone. | |
| 41 | | | |
| | 16 | Shales. | |
| 25 | | | |
| | 25 | No. 5. Wreford limestone—the lower flint. | |
| 0 | | | |

| System | Description | Thickness | Elevation |
|---|---|---|---|
| Permo-Carboniferous. | No. 19. Green and gray shales, with fossils. | 14 | 355 |
| | No. 20. Thin limestones and shales, with *Monotis* in the limestones. | 33 | 341 |
| | Mostly covered. | 27 | 308 |
| | No. 23. Shales and occasional limestones, with fossils. | 35 | 281 |
| | No. 24. Hard, yellowish gray limestone, with *Fusulina*. | 6 | 246 |
| | No. 25. Shaly limestone, with some fossils. | 36 | 240 |
| | No. 26. Thin argillaceous limestone of laminated structure. | 9 | 204 |
| | No. 27. Gray limestone, cellular in middle. | 5 | 195 |
| (?) Carboniferous. | Various colored shales, alternating with argillaceous limestones. | 52 | 190 |
| | No. 34. Bluish and purple shales, with fossils near the middle of the bed. | 12 | 138 |
| | Blue, gray and greenish shales and laminated, light gray claystone. | 52 | 126 |
| | No. 37. Argillaceous limestones, with abundant fossils. | 18 | 74 |
| | Bluish shales and various colored clays. | 56 | 56 |
| | No. 40. Opposite mouth of Big Blue river. | | 0 |

| Elevation | Thickness | Description | System |
|---|---|---|---|
| 328 | 6 | No. 67. Blue and drab shales. | Permo-Carboniferous. |
| 322 | 1–3 | No. 68. Blue limestone, with lamellibranchs. | |
| 321 | 21 | Shales and thin limestones. | |
| 300 | 3 | No. 76. Blue and gray limestone, with *Monotis*. | |
| 297 | 11 | Shales and limestone. | |
| 286 | 38 | No. 79. Shales and thin limestones, with fossils. | |
| 248 | 6 | No. 80. *Fusulina* limestone. | |
| 242 | 31 | No. 81. Blue, purple and green shales, with fossils. | |
| 211 | 6 | No. 82. Cotton rock—bluish marls. | |
| 205 | 5 | No. 84. Dry bone limestone. | |
| 200 | | *Base of Lower Permian.* | |
| | 200 | Shales and limestones. | Carboniferous. |

| | |
|---|---|
| Manhattan beds. | Permo-Carboniferous. |
| Upper Coal Measures. | |

* In compiling these sections, when two numbers are given to represent the thickness of a bed the lesser one is used in determining the complete thickness of the section.

† Professor Swallow did not state which bed of his section is the lowest one exposed at Manhattan, but I assume that the lowest mentioned at Manhattan (number 118) is at water level. The total thickness of the beds given between number 118 and the base of his Permian (number 84) is 200 feet.

‡ The heavy lines in the sections indicate the line of division between the systems, or call attention to the correlation of the same beds in the different sections.

## Conclusion.

The final correlation of this series of rocks is one of the most interesting problems yet to be settled in American geology. In this paper the writer has attempted to give a brief review of the previous work and opinions of the geologists who have studied this series of rocks; has called attention to the important horizons of their sections, stating where they may be seen in the field, and has noted the portions of their work which later studies have made particularly important. In a following paper the writer hopes to take up the question of the general correlation of these beds and to consider especially their fauna with regard to range and distribution of species as an aid to the determination of the age of these formations.

WASHBURN COLLEGE, TOPEKA, KANSAS, *June* 16, 1894.

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# THE EXTENSION OF UNIFORMITARIANISM TO DEFORMATION

BY W J MCGEE

*(Read before the Society August 14, 1894)*

CONTENTS



## The known Movements of the Earthcrust.

### *OBSERVED MOVEMENTS.*

Holland is sinking with respect to sealevel and the ocean is encroaching on its shores. Dikes are built to protect the land, and from generation to generation they have been raised higher and higher until now fields and meadows lie five or ten yards below the level of the ocean. The sinking has progressed variably, yet without complete interruption, since the beginning of local history, and the measurements of a thousand years indicate that it ranges from 0.09 to 0.75 of a meter per century, the more exact measurements since 1732 giving a mean of 0.26 of a meter for each hundred years. No horizontal movement of the terrestrial crust has been detected in connection with this vertical movement.

In 1819 a severe earthquake devastated the delta of the Five Rivers in western India, and throughout an immense area the quaking land sank and the ocean stretched over it to a depth of from one to three yards, while the vast salt marsh known as the Rann of Kach was greatly extended; but no appreciable horizontal movement accompanied this vertical sinking of the land about the mouth of the Indus.

The New Jersey shore, like that of Holland, is sinking and the ocean is encroaching upon it. The movement is slow, so slow that the rise of the waters is perceived only when a great storm beats on the shore, undermining the towns and throwing up sand beaches across the estuaries, each farther inland than its predecessor; yet millions of dollars are lost by the invasion of the ocean during each decade, and from generation to generation it is found that the headlands are eaten away, that tidal marshes have become sea-bottom, that upland trees are poisoned by the brine, and that the estuaries slowly but surely creep upstream, while the sandbars by which they are bounded follow with equal pace; and the invasion has continued from century to century until the ocean flows over the stumps and roots of brine-killed upland trees and until whole forests have been drowned and buried in tidelevel slime, so that the mining of buried forests was long a profitable occupation of the Jerseymen. So far as the records of history and of submerged forests go, they indicate that the sinking of the land is continuous at a rate of some two feet in each century; yet no unmistakable record of horizontal movement has been found.*

The Gulf of Mexico is encroaching on its northern shores; within the century many historic villas overlooking its waters have been sapped, while others have been saved only by removal; l'Isle Dernière with its aristocratic living freight was swallowed by the insatiate waters, and other islands of lesser note have disappeared forever in the gulf. Here, as on the New Jersey coast, upland trees have been poisoned by the brine and their taproots are found in the bottom of the main even below low tidelevel; and the estuaries march slowly but ceaselessly upstream, while the bounding sandbanks follow or else remain behind as great keys skirting the entire coast, probably submerged and rebuilt further inland from millennium to millennium. The rate of the invasion of the waters, or of the sinking of the coast on which the invasion depends, has not been measured, though the vertical movement would seem to be as rapid as that of Holland or New Jersey; yet no associated horizontal movement has ever been detected.

*It has been shown by the writer (Geology of the Head of Chesapeake Bay: Seventh Annual Report of the U. S. Geological Survey, 1888, p. 620 et seq.) that the topography and structure of the inland margin of the coastal plain suggest a movement with a lateral element analogous to that of a landslip; but the horizontal movement has never actually been detected.

The three remaining pillars of the temple of Serapis, near Puzzuoli, on the Mediterranean shore, with their molluscan borings and the marine deposits in which they were half imbedded, yield a record of vertical oscillation through a range of more than a score of feet within half a millennium; yet even in this volcanic and earthquake-ridden region the known movement is almost wholly vertical, the slight inclination of the pillars suggesting unequal settling rather than horizontal movement.

In 1811–'13 the New Madrid earthquake shook the Mississippi valley, with about one-third of our territory. An area of some thousand square miles sank, and much of it was converted into swamps and a part into lakes, while an area of some hundred square miles was lifted athwart the great river, temporarily reversing its flow and forming other lakes. The downward movement has not been measured, but must have amounted to some feet or yards over thousands of miles. The relative upward movement in the lifted area averaged 15 or 20 feet; yet there is no record, historic or geologic, of horizontal movement other than that of the walls of fissures and of the landslips along the river bluffs.

These are but instances which might be multiplied indefinitely. On every continent some coasts are found to be sinking or rising with respect to tidelevel, and after most great earthquakes the land is lower or higher than before. It is the teaching of common observation by laymen, as of refined observation by surveyors, that the coast changes secularly during generations, spasmodically during earthquakes, and with every step in the refinement of observation the number of shifting shores is increased. The shifting of the shore is not, indeed, in all cases traced to corporeal movement within the earth, yet in some cases the connection has been established, and with every advance in the progress of scientific interpretation the number of such cases is augmented; but in every case, on every shore of every continent on the globe, the earth movement is found to be chiefly or wholly vertical, only subordinately if at all horizontal. So it is the common experience of man throughout the world that the observed earth movements are essentially vertical.

### *MOVEMENTS INFERRED FROM SHORELINES.*

The Scandinavian coast is girt with ancient strands in which sea-shells of living species are found, and these strands are interpreted by the layman and the learned alike as the work of the waves when the land was lower than now; yet there is nothing to indicate and everything to disprove that the land shifted laterally as it lifted vertically. Minnesota, North Dakota and Manitoba are traversed by regular banks recognized by all students as the shorelines of the ancient lake Agassiz, which was bounded on the north by the Pleistocene ice. Evidently these shore-

lines were once horizontal, but now they are warped in such manner as to demonstrate differential vertical movement of the earthcrust. The differential movement recorded in the warped beaches amounts to scores of yards; yet there is no shadow of record of any horizontal movement connected therewith. The region of the Great lakes is similarly traversed by terraces and strands marking several stages in the development and destruction of interior lakes and ocean-connected bays. From these shore-marks an elaborate history of the later episodes of the Pleistocene, of the melting of ice and the birth of rivers, of the formation of lakes and the draining of basins, has been read; yet no part of the record is of greater interest than that which tells of the warping of the earthcrust as the ice retreated. This warping reached scores, and in some cases hundreds, of feet; but so far as known it was entirely vertical, and there is nothing to attest and everything to disprove horizontal movement of appreciable amount.

These instances of earth-warping recorded in ancient beaches and terraces might be multiplied indefinitely, and all are consistent and point in the same direction—all tell of vertical movement, none tell of horizontal movement. The inferences by which the record is interpreted are direct. The wave-work inferred is like the wave-work observed, and the oscillation inferred is in no way different from the oscillation observed. So the testimony of the ancient beaches is in harmony with the observations of laymen and surveyors, and attests corporeal movement in the earthcrust which is chiefly or wholly vertical, only subordinately if at all horizontal.

### *MOVEMENTS INFERRED FROM LATER FORMATIONS AND UNCONFORMITIES.*

The coastal plain of southeastern United States is built of a succession of formations, each commonly separated from its neighbors by unconformities, and under the consistent interpretation of all students the formations are records of submergence beneath oceanic waters, the unconformities records of emergence above tide and of sculpture by rain and rivers. The latest record of the past is one of higher level than the present, when the rivers cut channels that are now partly drowned by the encroaching Atlantic; and there are indications that the subsequent sinking of the land was not everywhere the same, but that the earthcrust warped in some measure. The recent subsidence reaches scores or even hundreds of feet, yet there is no measurable record of concurrent horizontal movement. The next earlier episode recorded by the deposits and unconformities of the coastal plain is one of submergence, during which the Columbia formation (or the earlier portion of that deposit, if it be divided) was laid down. This submergence varied in different

parts of the province, through strong warping of the earthcrust, from only about 100 feet to more than 700 feet; yet the entire record is essentially one of vertical movement alone. A still more remote record is found in the Columbia-Lafayette unconformity, which proves that the land rose unequally, in a part of the province only a little over a hundred feet, in other parts several hundred feet, and in one part nearly or quite a thousand feet higher than now; yet there is no record of horizontal movement connected with this wide vertical oscillation. Still earlier episodes are recorded in numbers; yet all records are essentially alike—all indicate vertical movement through hundreds of feet, all indicate that the earthcrust warped so that the movement varied from place to place, all fail utterly to indicate appreciable horizontal movement. Moreover, in this province of highly significant geologic records the vertical movements of the later half of geologic time fall into rhythmic series of oscillations, each beginning strong and gradually dying out, while at the same time the best known warpings fall into a definite system in which the axes of relative stability and of maximum movement persisted through several successive episodes; and this impressive harmony of vertical movement expresses a formal if not a physical law of epeirogeny in which lateral movement plays no part. Still further, the movements extended beyond the limits of the province and are now known to represent a system of vertical undulations affecting all of southeastern United States.*

The formations and unconformities of the American coastal plain give but an instance which might be repeated, albeit less completely, along the coastal zones of other continents, and the testimony of all the coastal zones of the world is alike—all tell of vertical oscillation, none tell of commensurate horizontal movement in the earthcrust. The formations and unconformities are interpreted by direct inference, by inference in

*These movements have been summarized elsewhere (Compte-Rendu du Congrès Géologique International à Washington en 1891 (1894), p. 165), as follows: "In general the post-Jurassic history of the subcontinent represented by southeastern United States is one of progressive uplift along the Appalachian axis, progressive downthrow about the periphery (extending from the Atlantic coast through the Gulf of Mexico and some distance northward in the Mississippi valley), with concomitant seaward tilting of the Piedmont areas. The movement was not uniform, but spasmodic. Each throe was complex, including an initial warping and a series of oscillations. The first movement in each throe was (*a*) relative uplift of the Appalachian axis and downthrow of the periphery, coupled with (*b*) depression of the entire area perhaps to such an extent as to counterbalance the axial uplift, thereby (*c*) submerging a considerable part of the subcontinent and (*d*) stimulating degradation over the interior. The second movement in each throe was general elevation, without recognized tilting, followed by gradual subsidence, and, in some cases at least, a diminishing series of minor oscillations. The subsidence and elevation of each throe were coördinate, profound subsidence being followed by high elevation; limited subsidence by slight elevation. This law of continental movement, which is singularly simple and rhythmic, is apparently exemplified in all of the oscillations in which the coastal plain and the contiguous land area have participated."

kind alone; the formations are like the observed products of submergence, the unconformities are like the observed products of running waters, the movements inferred are like the movements observed, and thereby the danger of error in interpretation is greatly reduced, if not entirely eliminated. So the record of the coastal plains is in harmony with observation on subsiding coasts and with direct inferences from uplifted strands—it is a record of corporeal movement within the earthcrust which is chiefly or wholly vertical, only subordinately if at all horizontal.

### *MOVEMENTS INFERRED FROM THE CONTINENTS.*

Throughout an area of some 150,000 square miles in eastern United States, comprising the Appalachian and Piedmont regions, the Adirondack dome, and the New England hills, as well as throughout areas of perhaps 50,000 miles in the Lake Superior region and 25,000 square miles in the Ozark region, the rocks are strongly contorted and more or less metamorphosed. Throughout an area of about 125,000 square miles on the Pacific slope, including the Coast range and the Sierra, together with the Klamath and other mountain systems, the rocks are similarly deformed, and throughout a gross area of perhaps 150,000 square miles, embracing the Rocky mountain region and certain Basin ranges, the strata are in large part affected by flexures and thrust faults. There is thus an aggregate area of some 500,000 square miles, or one-sixth of the territory of the United States (exclusive of Alaska), which may be characterized as mountainous and in which the strata are flexed, thrust-faulted, and otherwise deformed in a manner similar to that in which smaller bodies are deformed by horizontal compression. This is the geologically aberrant fraction of our territory, the relatively small area in which the structure is exceptional and abnormal.

Throughout an aggregate area of perhaps 250,000 square miles, embracing much of the Great basin, with parts of the Columbia mesas on the north and the High plateaus on the south, the surface is submountainous and the strata are broken up into great tilted blocks bounded by normal faults. The deformation in this twelfth of our territory is explicable only as the product of predominantly vertical movement with a subordinate horizontal element in the direction of extension, and this inference is in accord with experience of movements similar in kind to those inferred in the Lone Pine and Sonora earthquakes. This is a partially aberrant fraction of the country in which the movements recorded in the rocks are normal in kind though exceptional in degree.

Throughout the remaining three-fourths of the United States the strata represent a succession of formations and unconformities analogous to

those of the coastal plain; as in the coastal plain, each formation is explicable only as a record of submergence; and each unconformity of the usual type is explicable only as a record of emergence, with sculpturing by rain and rivers. Throughout this area of 2,250,000 squares miles the strata are occasionally divided by faults hading to the downthrow, and therefore indicating horizontal extension. The formations and unconformities are many, and collectively they constitute a complex record of continental oscillation, the amplitude of which is to be measured by thousands of feet or even (in the borders of the mountainous regions) by vertical miles; yet throughout this area of three-fourths of our territory the record gives only subordinate indication of horizontal movement in the earthcrust. The great, oft-repeated, and long-continued movement was vertical, the horizontal movement was relatively slight and, so far as it goes, indicates extension.

The case of the United States is one of many. In every great continent on the globe there is a relatively small area of mountains composed of strongly deformed rocks, and a relatively large area in which the strata furnish a record of vertical oscillations of wide amplitude with little horizontal movement. One-fifth, or perhaps one-fourth, of the land area of the globe is mountainous and deformed; the larger fraction is non-mountainous and not deformed, at least superficially, *i. e.*, in normal condition; and thus the normal record of geology is essentially one of vertical movement in the earthcrust. The inferences involved in interpreting the record are direct, and hence subject to little error; the formations are essentially like those observed in process of accumulation, the unconformities essentially like the land-forms seen in process of sculpturing, and the coastal undulations are essentially like those measured in Holland; even the inference of stratic extension from normal faults is a simple application of geometry.

### *ESSENTIAL CHARACTERS OF EARTH MOVEMENTS.*

During recent years orogeny, or mountain-raising, is discriminated from epeirogeny, or continent-lifting, by many geologists. Orogeny is relatively local, temporary, exceptional; epeirogeny is relatively widespread, constant, general—*i. e.*, the former is the aberrant or abnormal, the latter the characteristic or normal. Moreover, the processes of orogeny (except of the subnormal Great basin type) transcend experience, and are not inferred directly from observation but only from products by indirect analogy, while the processes of epeirogeny are subjects-matter of experience, and those not seen are inferred directly from observed processes. Accordingly it is legitimate, albeit unusual (as set forth later), to confine attention to the normal and the relatively definite in

the consideration of terrestrial deformation. Excluding those montanic regions in which the rocks are crumpled, then, it may be affirmed that the prevailing movements of the earthcrust are of the kind observed along a score of coasts and inferred from raised beaches and from formations and unconformities—that the normal corporeal movements of the earth are essentially radial, only subordinately tangential.

## Methods of Acquiring Knowledge.

### *THE EMPIRIC METHOD.*

There are three interrelated modes of acquiring empiric knowledge concerning the processes of nature: Stated in the inverse order of development, the first and most trustworthy mode is direct observation; the second mode is inference through homology, or reasoning from the like; the third and least trustworthy is inference through analogy, or reasoning from the unlike.

The value of direct observation depends on training. In order to be fruitful, observation must be fertilized by inference, while inference can be made safe only through frequent checking by comparison with the facts, and trained observation is a composite process in which inference plays an essential part.

The value of inference through homology, or reasoning from like to like, depends on several conditions: The first condition resides in the closeness of similarity among the things compared in their five primal attributes of number, extension, motion, duration, and serial succession; other conditions reside in habits of observation or in methods of interpreting the things compared, and still other conditions reside in the degree of accuracy of the pictures, or records, or concepts, of the things compared. Thus, while inference through homology is the safest of all reasoning, there are nevertheless, in this mode of acquiring knowledge, degrees of trustworthiness, grading down from a certainty hardly below that of trained observation to an uncertainty hardly above that of inference through analogy.

The value of inference through analogy, or reasoning from the like to the like only in part (and therefore in strict sense to the unlike), similarly depends on a variety of conditions. The primary condition resides in the number and variety of things compared or contrasted, and other conditions reside in habits of observation and in methods of interpreting, as well as in the accuracy of records and concepts. Thus reasoning through analogy does not directly tend toward the identification of things, but rather toward the multiplication of ideas; and while analogic inference sharpens and thereby improves observation, it adds little

directly to the sum of systemic knowledge, and its product is always indefinite and uncertain.

When the processes of reasoning by analogy and homology respectively are compared they are found to be antithetic—to stand in the relation of the face and the obverse of the same shield. Analogic inference (or reasoning from what is recognized to be like in only one or a few attributes) is discursive and suggestive, leading on the one hand to discrimination and thus to refinement of observation, and on the other hand to the invention of hypothesis; while homologic inference is incursive and constructive, leading on the one hand to identification and thus to refinement of observation, and on the other hand to the elimination of aberrant observation and incongruous hypothesis, or to generalization. Thus analogic inference is analytic, homologic inference synthetic; the one makes for the accumulation, the other for the assimilation of observations; the one leads to speculation, the other to generalization; the first adds to the quantity, the second to the quality of knowledge.

Empiric knowledge, like knowledge of a higher order, is possession and arrangement of facts. When the facts are few retention is easy, and the facts are accessible for comparison with little arrangement; when the facts are many retention is more difficult, and the facts can be kept accessible only by definite arrangement; and in this way classification grows up with the accumulation of knowledge. Again, when the facts are few and the classes small the arrangement may rest on one or, at most, a few attributes without inconvenience to the user, but when the facts are many and the classes large it is necessary to subdivide the classes by additional attributes, else the user is swamped beneath the burden of his own possessions; and in this way classification becomes more and more refined with the accumulation of knowledge. Now, in the beginning of the acquisition of knowledge through observation there is little need for arrangement with a view to retention, and accordingly nearly all effort is directed toward discrimination, and contrasts are sought and differences magnified through the process of reasoning from the unlike, and thus analogic inference is developed. Later, when the facts of observation are too numerous for retention without arrangement, a larger and ever-increasing share of effort is withdrawn from acquisition and devoted to assimilation, and comparisons are made and resemblances sought, to the end that like may be grouped with like, and thus homologic inference is developed to the partial exclusion and legitimate regulation of analogic inference. Accordingly, analogic reasoning is the more primitive, homologic reasoning the more developed.

The body of empiric knowledge, like that of higher order, reacts on the method of acquisition in every stage, and thus there is a normal progres-

sion in classification and in reasoning from the primitive to the more highly developed. In the beginning of history men knew few facts, yet they vaguely recognized many categories and speculated wildly; in the beginning of empiric philosophy the wise men had richer store of facts and fewer categories, yet in their classification they continued to seek contrasts and divide by successive differences; in the beginning of a higher philosophy the learned possessed such wealth of facts that they were fain to group by resemblance rather than divide by difference, to infer through homology rather than analogy—and in this way science was born. These stages of knowledge and of acquisitional method are represented in the history of the race, in the early history of each branch of science, in epitome in the intellectual growth of each individual; and the stages are none the less veritable that they overlap and interosculate in endless complexity, especially in the higher part of the series.

### *THE SCIENTIFIC METHOD.*

There is a fourth method of acquiring, or rather of organizing, knowledge, which is thereby rendered scientific, namely, reasoning by identity in serial succession or genesis, which may be styled (in the broader sense as well as in the special sense in which the term is already used) inference by homogeny. The value of homogenic inference depends on the absoluteness of the identity recognized, together with a wide variety of other conditions, for this method of reasoning involves identification through partial likeness or through analogic inference, as well as grouping by resemblance or homologic inference.

When the three processes of reasoning are compared it is found that homogenic inference is the most highly developed. With the multiplication of facts retention becomes more and more difficult, arrangement more and more necessary; and when the distinctions resting on the more extrinsic resemblances themselves based on the simpler attributes become insufficient, intrinsic relations based on the more complex attributes are sought; and since the most complex attribute of things thus far known in the cosmos is serial succession, this attribute has consciously or unconsciously been seized upon as a basis for the most refined classification Thus homogenic inference is the legitimate offspring of homologic and analogic reasoning and rises to a higher plane than either; and the scientific method of extending knowledge comprehends all of the empiric methods, with the addition of a higher method.

In the scientific as in the empiric knowledge, the store of facts reacts on the method by which the facts are garnered, and thus the normal progression in classification and reasoning is continued. In the more complex branches of science acquisition began in discrimination, pro-

ceeded to generalization, and then rose or is rising to unification in families or genetic groups. In the days of Aristotle the method of classification was successive division by difference, then under the influence of Bacon and Linnæus the method became one of successive grouping by resemblance, while Darwin and his successors introduced the method of classifying by genetic relation or consanguinity; and during our own generation descriptive science has given way largely to systemic science, and thereby species and genera are increasing less rapidly in number than in fullness of meaning.

The several stages in development of the modes of acquiring knowledge are none the less real in that they overlap and blend in the development of the branch of science, in the intellectual expansion of the individual; and they are none the less veritable that the empiric stage grades into the scientific stage so imperceptibly that no sharp line may be drawn between; for such is the law of becoming, by which all things in the universe are made.

## Growth of Knowledge of the Earthcrust.

### *THE STAGE OF SPECULATION.*

In geology, as in other branches of knowledge, the four methods of acquisition—observation, discrimination, generalization and genetic classification—have been employed in normal order. At first the individual geologist, enriched by heritage of observing faculty and reasoning power developed through generations, began to see more in the rocks than his ancestors were able to perceive, and quickly passed into the first stage of reasoning. Differences in color, form and size were detected, and discrimination progressed and grew into speculation, and the ratio of hypothesis to observed fact grew large, as is ever the case among laymen and the illiterate. During this stage attention was commonly attracted and held only by the rare or remote, and the facts near at hand were ignored even if they were perceived, and so the primitive geologist found matter of interest chiefly in deep mines and distant mountains, and was blind to the normal strata beneath his feet, to the residua forming the soil on which he lived, to the alluvial and glacial deposits in which the later history of the earth is recorded. Throughout this stage the body of observed fact was meager, while "theories of the earth" abounded, though few were so tangible as to be preserved in definite form.

Such was the stage of reasoning from the unlike in the development of geology, yet it was the necessary precursor of a higher stage, and has its parallel in each branch of knowledge. The processes of thought were

predominantly deductive and involutionary, and knowledge expanded on a relatively low plane, increasing in quantity rather than improving in quality. It may be called the stage of speculation.

### *THE STAGE OF RATIOCINATION.*

The geologist of the second generation, like his predecessors, began with observation, proceeded to discrimination, and gradually rose to homologic reasoning, and reaching this plane he was able to group facts and eliminate crude hypotheses, so that the ratio of hypothesis to fact diminished. Concurrently the field of geology widened, and the geologist found matter of interest not simply in deep mines and distant mountains, but in the undisturbed strata nearer at hand, and even the superficial deposits and the products of decomposition of rocks, and eventually the land forms into which the strata and residua are sculptured, received attention. So during this stage the progress of knowledge concerning the earth was from the indefinite to the definite, from the vague to the trenchant, from lax speculation toward exact reasoning, from hypothesis to theory; yet there was a heritage of crude hypothesis (of which a part persists) by which progress was hindered.

Such was the second stage in the progress in knowledge concerning the earthcrust. During this stage many fruitless hypotheses were eliminated, many fruitful theories formulated. The attendant intellectual processes were largely inductive and involutionary, and knowledge rose to a higher plane, improving in quality as it grew in quantity. It may be called the stage of theory.

### *THE STAGE OF GENETIC CLASSIFICATION.*

The third stage in the development of geology was initiated when Lyell and his disciples perceived that the river carves its own valley, that rain and rills sculpture the hillside, and that oceans, bays and lakes line their own bottoms with stratified deposits homologous with rock formations. One of the first fruits of this extension of knowledge was increased interest in the commonplace and simple; the geologist found records of significant process in the flat-lying strata of the neighboring hill, in the superficial deposits mantling the valley, in the forms of the land, eventually even in the products of rock decay. Another result was the multiplication of observers and the subsequent application of the science to the promotion of human weal through mining and agriculture. During this stage the body of observed fact has been and is increasing with unprecedented rapidity, and with the accumulation of fact there has been some increase in hypothesis; yet the ratio of hypoth-

esis is ever diminishing and the trustworthiness or exactitude of the science constantly increasing.

Such is the stage of reasoning through identity in succession or homogeny. It may be called the stage of genetic classification or the stage of uniformitarianism. The concomitant intellectual processes are a just combination of deduction and induction, of evolutionary and involutionary reasoning, and knowledge at once expands and improves, increasing constantly in exactitude as well as in extent. The stage has fully come for stratigraphy, for gradation (or that branch of dynamic geology which deals with particle movements), and for paleontology; but it has not yet come for that branch of dynamic geology which deals with mass movement in the earthcrust.

### *THE HERITAGE OF HYPOTHESIS.*

During the earlier stages in the growth of geologic science, when the observing faculty was ill trained, and when students reveled in florid speculation based on scant observation of the rare and remote, two noteworthy hypotheses sprang from analogic reasoning and gained wide acceptance: one was the hypothesis that rivers flow in catastrophic fractures in the earthcrust; the other the hypothesis that the great features of the globe were produced by lateral stresses and movements in the earthcrust due to shrinking of the nucleus of the planet. Now that both hypotheses have been tested by comparison with facts and by more advanced reasoning, it is seen that they had much in common. Both appealed to the unknown in nature; both ignored the daily procession of events in the degradation of the land and the rhythmic rise and fall of shores; both represented rude analogy between things unlike in kind and magnitude, for in both cases the analogy was found in the fracture or deformation of small bodies unlike the earth in constitution. In so far as they were based on fact, both hypotheses rested on the aberrant rather than the normal, the local and exceptional rather than the general; and while they were measurably and temporarily useful in stimulating thought, both diverted attention from the facts of nature and thereby tended in some degree to retard the progress of knowledge. No man ever saw a great valley formed by fracture of the earthcrust, nor did man ever observe a lateral movement in the earthcrust (save possibly in connection with a dominant vertical movement), though all men saw or might have seen the endless activity of the streams in excavating valleys, the endless vertical oscillations about the shores of the Mediterranean, North sea, the bay of Bengal and Arabian gulf; yet in the dim light of dawning earth-science the actual processes were overlooked and

figments of budding scientific imagination were substituted for facts of observation. The two primitive hypotheses have much in common, yet they are unlike in an important particular—one has been abandoned so completely that it may be questioned whether the pendulum of opinion has not swung back too far; the other is retained today, perhaps justly in its limited application to orogeny but certainly in violence to the facts of epeirogeny, by many geologists.

There was reason for the early abandonment of the fracture theory of valleys: It is an easy step from the perception of channel-cutting to the recognition of valley-carving, and another easy step to the homologic inference that the hill and dale of the countryside were fashioned by the beating rain and the flowing rill; the agency is tangible and visible; the process though variable in rate is constant in kind and in action; there is no occasion to break the chain of direct homology in process by appealing to the analogy of unlike things. The abandonment of the hypothesis, or, rather, the substitution of more exact observation and advanced reasoning, marked an important epoch in the development of geology, yet the advance was natural, and would have been made ere this even if the light of Lyell's genius had not burned.

The long retention of the contractional hypothesis of deformation is not surprising: the oscillations of the earthcrust are slow, in most cases hardly to be detected without refined surveys. In many cases they are confined to local shores, where they are obscured by tides, wave-action, and the beating of storms. The surveys by which they are detected are commonly made by men trained in abstract concepts to the extent that they have no living sense of terrestrial activity and either ignore or deny the movement their measurements attest; there is no tangible, visible agency like the ever-active river to attract attention and stimulate imagination; there is little in the actual movement of the earthcrust for observation to seize, and until observations have accumulated, no clearly defined facts for homologic inference to grasp. Moreover, it is an easy step in analogic reasoning from the buckled beam, wrinkled roof-plate and crumpled model to the flexed and thrust-faulted stratum, an easy analogic step from the shriveled apple to an hypothetic corrugated planet; there may indeed be nothing, probably there is nothing, in common between the miniature wrinkling of the model in the laboratory and the grand deformation of a great planet, yet no chasm is too broad for the bridge of analogic inference. There is nevertheless little real reason for the persistence of the hypothesis, since it is without basis in direct homologic inference; no human eyes have seen horizontal earth movements, save possibly as a subordinate element in the vertical movement, and at

the best the hypothesis rests on a double inference: the first through homology in the laboratory, the second through analogy between laboratory product and natural process. There is no direct line of reasoning in its support, and there remain outstanding the ample and perpetual vertical oscillations of the earthcrust which the hypothesis is incompetent to explain.

### The Meaning of the Movements.

Vertical movements in the earthcrust have been recorded and sometimes measured by a hundred geologists in different countries, and the formations and unconformities of a score of geologic provinces have been interpreted through homology with observed oscillations by most geologists in every country. Thus there is a vast body of knowledge concerning movements in the earthcrust which demand explanation. Partial explanations have indeed been promulgated. Powell and Gilbert, under the inspiration of a magnificent field, have shown that unloaded areas rise and that loaded areas sink, yet this triumph of homogenic reasoning does not indicate the source of the energy required to perpetuate the mechanism. Dutton has formulated the suggestive law of isostasy, but it may be questioned whether this law in its simple form is competent to explain the greater oscillations. It has been shown elsewhere that the areas of deposition throughout the world, so far as not complicated by other conditions, are areas of subsidence, and thus that the generalizations of Powell, Gilbert and Dutton are sustained by present as well as past agencies;* the corporeal movements of the earthcrust have been discriminated and grouped as (1) antecedent and (2) consequent,† and the latter have been shown to be governed by and the former to transcend the law of isostasy; yet the primary corporeal movements of the earth await a consistent and quantitatively adequate explanation.‡

It is not the purpose to either affirm or deny the validity of the contractional hypothesis as applied to the abnormal quarter of the land surface of the planet in which the rocks of each age are crumpled and thrust, though it may be suggested that a simpler hypothesis will yet be found along the line long ago suggested by Herschel and more recently developed in connection with the modern displacement of our coastal plain; § it is the purpose to question, and indeed to deny, the applica-

* The Gulf of Mexico as a Measure of Isostasy: Am. Jour. Sci., 3d ser., vol. xliv, 1892, pp. 177–192.

† Some Definitions in Dynamical Geology: Geol. Mag., Decade III, vol. v, 1888, pp. 489–495.

‡ It may be observed that Powell has formulated, but not yet published, an apparently satisfactory explanation of these antecedent vertical movements. The author has offered a tentative explanation (Bull. Minnesota Academy of Sciences, vol. iii, 1888, pp. 191–206), but the adequacy of the cause indicated is open to question.

§ Seventh Annual Report of the United States Geological Survey, 1888, pp. 626–634.

bility of the contractional hypothesis to the known earth movements *per se.* The deposition areas of the great rivers are subsiding; many lands, particularly those from which the Pleistocene ice is not long removed, are rising differentially; the coastal zones of many countries are a record of repeated oscillation; the strata of the normal three-quarters of the continent afford voluminous testimony of undulatory rise and fall; even the mountain ranges are rising vertically. The dislocations displayed by three-quarters of the earth indicate stratic extension; only one-quarter indicate contraction. It is vain to explain the seen in terms of the unseen; and the time is gone by for the primitive appeal to the rare and remote in explanation of the common and the near at hand, to the imaginery in explanation of the real. The vertical oscillations of the normal earthcrust constitute a vast body of well ascertained fact; the rise and fall of the land during the geologic past, as in the present, is hardly less firmly established than the endless action of running waters. Already these characteristic movements are partly within the domain of the most advanced geologic science in the form of genetic classification; yet earth-science will not be complete until the uniformitarianism introduced by Lyell embraces the mass movements as well as the particle movements of the earthcrust.

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# REVIEW OF OUR KNOWLEDGE OF THE GEOLOGY OF THE CALIFORNIA COAST RANGES

BY HAROLD W. FAIRBANKS

*(Read before the Society August 15, 1894)*

CONTENTS.

## Scope of the Paper.

In the following article it is intended to set forth, so far as is possible with the information at hand, the present state of our knowledge of the geology of the Coast ranges of California. The central theme in the presentation will be a discussion of the evidence supporting the view of the pre-Cretaceous age of the uncrystalline basement rocks of this region. The evidence treated of will deal partly with some results of recent field-work in the southern portion of the area and partly with a more detailed restatement of the conditions found to obtain in northern California. A brief summary will also be made of the characters of the oldest rocks in the Coast ranges—the granites, crystalline schists and limestones—as well as of the Cretaceous and Tertiary formations, and of the disturbances which have taken place, as indicated by the relation of these formations to each other.

It is with no intention of putting forth categorical statements concerning disputed questions that this article is prepared, but of giving more definite and explicit reasons for some previous views published by the writer in the American Geologist.* Many of the opinions therein ex-

* American Geologist, vol. ix, 1892, pp. 153–156, and vol. xi, 1893, pp. 70–84.

pressed seem to him to have been more completely substantiated by the results of field-work since their publication.

Great misconceptions have existed in regard to the real geologic conditions existing in the Coast ranges, both as to their age as well as to their relation to the supposed older range, the Sierra Nevada, and it is hoped that some light can be thrown on these questions.

## The Term Coast Ranges.

### *DIFFERENT GEOLOGISTS' CONCEPTION OF THE TERM.*

The designation Coast ranges as applied to that series of mountains bordering the coast of California is a very indefinite one and, owing to the topographic features, one which it is difficult to make exact. The term was first used by Fremont* in 1843. The names current among the Spaniards were those of individual ranges or peaks.

Dr Trask, in the opening of his first report,† speaks of the Coast ranges as extending from the forty-second parallel (northern boundary of the state) to the Mexican line. Later he proposed to divide the coast mountains south of San Francisco bay into Coast ranges proper, lying to the west of the Santa Clara and Salinas valleys, and the Monte Diablo range bordering the San Joaquin valley. In another place he says it is proposed by Blake to apply the term Peninsula range to all those mountains south of the thirty-fifth parallel north latitude to distinguish them from the Coast mountains, as well as the Sierra Nevada. In his second report‡ he emphasizes his belief that the Coast ranges should be considered as terminating in southern San Luis Obispo county, and that the Santa Ynez range, rising from the sea at point Arguello and extending in a direction more nearly east and west, belongs properly to the San Bernardino sierra.

J. S. Newberry,§ one of the geologists of the Pacific Railroad Survey, expresses the following view:

"As far north of San Francisco as cape Mendocino the Coast mountains have the same general northwest trend, and a more plausible supposition than that the Cascades form a continuation of the Coast mountains would be that the latter ranges terminate at cape Mendocino, and that the Coast mountains of Oregon were a continuation of the Sierra Nevada. It is not necessary to suppose this, however, but it is sufficient to consider the Coast mountains of Oregon as the Coast mountains of California, deflected from the trend which they preserve below cape Mendocino, and that the ranges of the coast and of the interior inosculate on either side of the forty-second parallel in the Calapooya, Umpqua and Siskiyou mountains."

* Exploring Expedition to Oregon and California, 1843.
† State Senate Documents, no. 9, 1854.
‡ State Senate Documents, no. 14, 1856.
§ Pacific Railroad Survey, vol. vi, p. 29.

Blake says: *

"In California the term 'Coast mountains' is generally understood to refer to the several ranges of mountains lying west of the Sierra Nevada, extending from Oregon to point Conception, and forming the barrier between the long interior valleys of the Sacramento and San Joaquin and the Pacific ocean."

Professor Whitney † defines the Coast ranges as follows:

"We consider all those chains or ranges of mountains to belong to the Coast ranges which have been uplifted since the deposition of the Cretaceous formation; those, on the other hand, which were elevated before the epoch of the Cretaceous are reckoned as belonging to the Sierra Nevada."

He says further that between the parallels 35 and 40 degrees north latitude there is no difficulty in separating the Coast ranges from the Sierra Nevada, and that it is only on geological considerations that the lines can be drawn; that the topography gives no clue. On the north he considers the Coast ranges terminated by the Klamath and Trinity rivers, while on the south he would extend them to San Diego county, including the San Gabriel and Santa Ana ranges.

Jules Marcou ‡ agrees with Dr Trask in that the Coast ranges should be considered as terminating in the southern part of San Luis Obispo county.

In Bulletin 33 of the United States Geological Survey, J. S. Diller says:

"For reasons hereafter given we will consider the northern end of the Sierra Nevada range to be in the vicinity of the North fork of Feather river before reaching Lassen's peak. From this point the elevation is continued for about fifty miles on the trend of the Sierras in the Lassen's peak volcanic ridge, which terminates near Pitt river. All south and west of mount Shasta belong to the Coast range. There appears to be a lack of appropriateness in including the ridges east of the Sacramento river, about the headwaters of the McCloud, in the Coast range, but it is evident that they are more closely related geologically to the Trinity and Scott mountains of the Coast range than to any portion of the Sierra Nevada."

He does not say whether it is used by him with the meaning simply of a topographic province, though that is the implication. In a recent note received from Mr Diller he emphasizes the statement that the term is used by him to indicate simply a "topographic province."

### *THE AUTHOR'S USE OF THE TERM COAST RANGES.*

From the foregoing quotations it will be seen how difficult it is to frame an exact definition of the term Coast ranges. The definitions given vary greatly, being based partly on age and partly on topography. Further

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* Ibid., vol. v, p. 138.

† General Geology of California, p. 167.

‡ Wheeler's Survey, 1876, p. 172.

on, the writer hopes to show the futility of attempting to frame a definition based on the age of the rocks, while it is evident at once that none can be given based on topography, because of the blending into other ranges at both ends.

The designation Coast ranges as it is used in the present article will include that series of mountain ranges extending west and northwest along the coast from the San Emidio region of crystalline rocks to and beyond the Oregon line. The San Emidio region, lying in northern Ventura county, is the meeting point of the Sierra Nevada and Peninsula ranges. In regard to the designation of the mountains in the northern part of the state, there seems to be no good reason for restricting the use of the term Coast ranges and substituting for it a local name. The usage of most of the earlier geologists is a good one, including, as they did, under the general term all that series of mountains near the coast, not only through California, but Oregon and Washington. Local names are perfectly proper and necessary for indicating particular sections, but because of the fact that there are included within the Coast ranges areas of such greatly different age, but not topographically distinct, no local or even general name can imply a geologic distinction. It would seem that the use of the term Klamath mountains is a convenient one and might well be adopted, but without implying any sharply marked geologic or topographic distinction. It would seem also that the use of the term Peninsula range for those mountains collectively which extend south from the San Emidio region into the peninsula of Lower California is a very convenient one.

South of the Santa Clara valley, in Ventura county, as far as the Santa Ana river, there are several mountain ranges the formation of which is largely Tertiary. These are, as a rule, not distinctly detached from the various mountains comprising the Peninsula range.

## Summary of Previous Work.

The earliest extensive geologic work in this state was undertaken in connection with the Pacific Railroad Survey—Blake, Marcou, Antisell, and Newberry, geologists. Considerable study was given to the Coast ranges, particularly south of San Francisco.

A little later Dr Trask spent a part of two seasons working out the geology of the Coast ranges.

In 1860 the Geological Survey of California was organized, and work was carried on intermittently until 1874. The results of the work in the coast region is to be found mainly in the volume devoted to general geology and in the two volumes on paleontology.

The monograph on the quicksilver deposits of the Pacific slope, prepared under the direction of Dr Becker, was devoted mainly to the Coast ranges. In it we have the results of the first detailed work done in this region.

More recently the work of J. S. Diller has extended into the Coast ranges in northern California. Dr A. C. Lawson, of the State University, has also made valuable additions to the geology of the central Coast ranges.

## Age and Relations of the Coast Ranges.

### *VARIOUS OPINIONS AS TO AGE.*

There has not existed much diversity of opinion in regard to the age of the Coast ranges until recently. This series of mountains has been held by all investigators to be of geologically recent origin. Dr Trask recognized the granitic formation (primitive) and the Tertiary. He says: *

"That the shores of the Miocene sea were primitive is proved from the fact that these rocks are imposed directly on the latter, thus demonstrating that its relative age with that of the northern and eastern chains is widely different and far more recent."

Jules Marcou says: †

"What is the principal age of this system of mountains? In a word, at what geological epoch did it make its appearance? I now think as I did in 1854, when I saw it for the first time, that it should be referred to the end of the Eocene Tertiary."

Antisell, ‡ in a foot-note, makes the following observation:

"The age of an axial rock combines the idea of the first upheaval through the hardened crust, and, to some extent, the period of its appearance above water, though not necessarily the latter idea. The Coast ranges were upheaved and lifted above the water posterior to the Miocene deposits."

Whitney states very plainly his ideas of the age of the Coast ranges in framing a definition for them; that is, that they date from the close of the Cretaceous. On page 16 of his volume on Auriferous Gravels he says:

"The most striking fact in regard to the Coast ranges is that this very extensive group of mountain chains is of comparatively very recent geological age. It is made up of Cretaceous and Tertiary strata, with no rocks older than these showing themselves in any portion of the complicated series of elevations which are properly included under the above designation."

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* State Senate Documents, no. 14, p. 19.
† Wheeler's Survey, 1876, p. 172.
‡ Pacific Railroad Survey, vol. vii, p. 24.

Dr Becker, while he has held that the granite and crystalline limestone may be older, has said that the upheaval between the Knoxville and Chico was the first distinctly traceable movement in the Coast ranges; and, farther:*

"The earliest determinable portion of the Coast ranges must then be considered as due to the same disturbance which added the gold belt proper to the Sierra Nevada."

H. W. Turner,† in a recent article reviewing the proposition advanced by the writer for the pre-Cretaceous age of the metamorphic rocks of the Coast ranges, offers the following hypotheses:

"1. That the granite, gneiss and metamorphic limestone of the Gavilan range and similar area elsewhere in the Coast ranges are Paleozoic and probably Carboniferous in age.

"2. That the phthanites, hardened sandstones and diabase are earlier than the Knoxville beds.

"3. That the serpentine, gabbro, and perhaps the glaucophane-schist, which is frequently associated with the serpentine, are post-Knoxville in age."

### *AGE OF COAST RANGES AS COMPARED WITH THAT OF THE SIERRA NEVADA.*

As compared with the Sierra Nevada, the Coast ranges have universally been considered the younger. Dr Trask, however, regarded the granite as of the same age as that of the Sierra Nevada. The references in geologic literature all give emphasis to the views of a great age for the Sierra Nevada and a comparatively recent date for the upheaval of the Coast ranges. Nearly all investigators have recognized the presence of granitic rocks; yet they have generally been considered of small extent and to have played an insignificant part in the development of the system. A great age for the granitic rocks has been postulated by some, while others have considered them younger than the Miocene. This almost universal opinion as to the age of the Coast ranges must be based on some prominent geologic fact, and that undoubtedly is the great development of the middle Tertiary in the region south of San Francisco; and while Cretaceous as well as older uncrystalline rocks are present, they have not been distinguished from each other, and by some not even separated from the Tertiary.

### *PHYSICAL AND GEOLOGIC RELATION TO THE SIERRA NEVADA.*

The chief difficulty in making an exact definition of the Coast ranges lies in the fact of the intimate geologic and structural relation to other mountain ranges, both north and south. Both Trask and Marcou in-

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*Quicksilver Deposits of the Pacific Slope, p. 211.

†American Geologist, vol. xi, p. 324.

cluded in the San Bernardino sierra the Santa Ynez range of Santa Barbara county. This has its origin near point Conception, and, blending with the San Rafael and Cuyamas mountains, extends eastward as a high and rugged range to unite finally with the San Emidio mountains.

Antisell* concluded, from the great elevation of the Miocene on the flanks of the Cordilleras (the San Gabriel and Sierra Libre ranges, terminating on the northwest in the San Emidio region), that the date of upheaval was the same as that of the Coast ranges. It seems to the writer that in the following quotation he expresses a truth the real significance of which has never been appreciated. He says:

"Nothing appears easier to trace than the relation of connection and continuity between the middle of the Coast ranges (San José and point Pinos) and the San Emidio, and between the San Emidio and the Cordilleras, a fact now for the first time stated and brought to light by the exploration of this survey, by which there has been traced a continuous granite chain from point Pinos, at Monterey bay, to the northwestern edge of the Cajon pass, terminating at the Kikel Mungo mountain."

This granitic chain to which he refers, although it was not found to be continuous on the surface, seems to represent a single axis. There is little doubt that future work will prove the unity of the whole body of granitic rocks and crystalline schists along this very regular northwest prolongation of the Peninsula range.

According to all observers, no topographic distinction can be made in the northern part of the state. Beginning at San Francisco bay, there is a gradual rise in the mountains northward to the Yallo Bally and other ranges in Humboldt and Trinity counties.

## Rocks of the Region and their Relations.

### *THE WHOLLY CRYSTALLINE BASEMENT COMPLEX.*

*Constitution and Distribution.*—The basement rocks in the Coast ranges consist of granite, crystalline schists and limestone. The exposed area of these rocks, although considerable, is small in comparison with the extent of this mountain region, but the part played by them in the development of its geologic history is important. The known outcrops were described in a former publication and illustrated by means of a sketch map.† It is sufficient to add, perhaps, that they seem to be arranged along two axes. To the eastern one belong the granite at point Reyes and vicinity, that of the Santa Cruz and Gavilan ranges, and the small area near Cholame valley, in eastern Monterey county. To the

* Pacific Railroad Survey, vol. vii, p. 90.
† American Geologist, vol. xi, pp. 71, 72.

western axis belong the Santa Lucia range and the series of low outcrops extending diagonally across the upper Salinas valley to the San José range. The latter is the axis which appears to be the direct prolongation of the San Emidio and Peninsula ranges. The greatest width of the crystalline rocks of the Santa Lucia range is about 25 miles; of the Gavilan range, 12 miles. It is probable that the crystalline schists connect underneath many of the intervening valleys, filled with later formations, and all taken together form one original axis of upheaval.

*Crystalline Schists and Limestone.*—The crystalline schists are chiefly confined to the Santa Lucia range, where they are more extensively developed than the granite. In fact, they form the greater portion of that very rugged region, from a few miles south of Carmel bay to the San Antonio valley. The range rises very abruptly from the ocean, forming the grandest scenery to be found anywhere along the coast of California. The crest is formed of limestone for a number of miles. It is remarkable for the extreme degree of metamorphism which it has undergone. It is generally coarsely crystalline, and contains in many places a yellow mica, green pyroxene, molybdenite and graphite. The limestone occurs in an irregular lenticular form, the different outcrops varying from but a few feet to several thousand in thickness. It is found both in the granite and in the schists; in the latter case conformable to the stratification. Quartzites, hornblende and mica-schists appear, and undoubtedly represent sedimentary terranes, but by far the greater part of the rock is gneissoid. How much of this latter structure is due to a movement of a granitic magma while solidifying and how much to an original sedimentary stratification is not certain. On the western slope of the range there are large areas of a rock consisting of quartz, feldspar and chlorite which may represent an older granite. The line of steep mountains west of the Salinas valley, between the Arroyo Seco and Placitos creek, also belongs to the Santa Lucia axis. Gneiss, mica-schist and small areas of limestone occur here. The amount of massive granite is small, being most prominent about mount Toro. A small area of limestone outcrops in the San José granite range. Crystalline limestone appears in many places in the granite and gneiss of the Gavilan range. It is much purer than in the Santa Lucia, consisting almost wholly of calcium carbonate.

*Granite.*—In only one locality in the Coast ranges—that about Carmel bay, described by Dr Lawson *—has the granite been studied in detail. This granite is remarkable for the large crystals of orthoclase, with inclusions of the other components. A number of slides were prepared by the writer of specimens from different granite exposures through the central and southern Coast ranges. Distinctly porphyritic granite of the Carmel

* Bull. Dept. Geology, University of California, vol. i.

type has not been found to be very extensive. About San Lucia, the dominating peak of the Santa Lucia range, occurs a granite with much the same character, but not so coarse. In the San José range it is also to be found. This latter granite, as shown in the slide, consists of orthoclase, triclinic feldspar, quartz and mica. The large orthoclase feldspars contain inclusions of the triclinic feldspars and brown mica. Grains of titanite are scattered through the rock. Nearly all the sections made agree in the possession of the following components: orthoclase, triclinic feldspar in varying amount (in one specimen exceeding the orthoclase), quartz, brown mica, occasionally magnetite, apatite and titanite. Most of the specimens show glassy feldspars. Small dikes of a younger granite, quite similar to that described by Dr Lawson from Carmel, are numerous in portions of the San José and Gavilan ranges. All the specimens of granite examined are remarkable for the absence of hornblende. H. W. Turner* has made the following note on the granite of the Gavilan range:

"This granite is very different from that of the Sierra Nevada. It appears to be, indeed, a typical granite, and, as shown by a thin section, is composed of plagioclase, orthoclase, quartz and biotite, while the granite of the Sierra Nevada is usually hornblendic, with very little orthoclase."

The collection of granites which the writer has from the Klamath mountains shows, in general, quite a different character from that of the Coast ranges farther south. They resemble more the Sierra Nevada type. Specimens gathered from different portions of the Trinity mountains are coarse grained, with an excess of hornblende over biotite, and possess a large amount of triclinic feldspar, in some specimens in excess of the orthoclase. The granite of the eastern part of the Salmon range is similar. Between Redding and Shasta and in the Castle Crags region the granite has quite a different character and may possibly be older.

*Evidence as to Age of the Basement Complex.*—Nothing definite is known as to the age of the basement complex. Among the older geologists opinions as to the age of the granite ranged from "Primitive" to "Miocene." It has been shown by Dr Becker† to underlie the Cretaceous, and it was considered by him that the rocks of the Gavilan range were much older, possibly Primitive. Dr. Lawson‡ has shown conclusively that Whitney's view as to its being intrusive in the Miocene is wholly wrong.

In a former paper§ the writer advanced reasons for belief in the intrusion of the granite in the pre-Cretaceous series of uncrystalline rocks. A

* American Geologist, vol. xi, p. 324.

† Monograph on the Quicksilver Deposits of the Pacific Slope, p. 174.

‡ Bull. Dept. Geology, University of California, vol. i, p. 18.

§ American Geologist, vol. xi, p. 71.

further examination showed that this was not the case, and that the granite in this part of the Coast ranges probably does not correspond to the Mesozoic granite in the Sierra Nevada. H. W. Turner has supposed that the granite of the Coast ranges may be of Carboniferous age. While there is no evidence against this, there is no reason for assuming Carboniferous rather than a greater age. Recent investigations have shown that there are probably at least two periods of granite irruption in California. That of Mesozoic age is known to form the greater portion of the Sierra Nevada, while in the Coast and Peninsula ranges much of the granite is supposed to be older.

The sedimentary portion of the basement complex in the Coast ranges is characterized, in common with similar rocks in the Peninsula range, by an extreme degree of metamorphism. The past season large areas of limestone in the Santa Lucia were carefully examined, without discovering any traces of fossils. No outcrops were seen which were not so crystallized that it would seem impossible for fossils, if they ever existed, to have been preserved. No fossils of the Triassic or Jurassic have yet been detected in southern California, still those obtained by the writer from the Santa Ana mountains which were determined as Carboniferous may upon closer examination prove to belong to the Trias. It does not seem at all impossible that the crystalline schists and limestone of the main portion of the Peninsula range, as well as of the Coast range, are much older than the Carboniferous. The granite magma has been injected into these schists, and of course is younger. The presence of none but the most highly metamorphosed rocks in this series in the area under discussion would indicate a great amount of erosion, for which protracted intervals of elevation above the sea would be necessary. If this were not the case it would seem probable that in some portion of this crystalline axis less metamorphosed rocks should occur. Too little is yet known about the stratigraphic position of the slate, shale and limestone of the Santa Ana range to say whether or not they are to be correlated with the extremely metamorphosed schists. It is quite possible that there are granites of different age in this portion of the Peninsula range. As a result of our present knowledge it can be safely said that in that portion of the Coast ranges between point Reyes and San Emidio there is no evidence of Mesozoic granite, but that the whole basement complex is as old as the Carboniferous, and perhaps much older.

*Relation of Basement Complex to oldest noncrystalline Rocks.*—The relation of the basement complex to the oldest noncrystalline rocks, which the writer has termed the pre-Cretaceous for lack of better evidence as to their exact age, has been difficult of determination. The difficulty results

partly from the excessive development of the Tertiary, thus hiding the contacts, and partly from the almost universal tendency to the erosion of canyons along this line. The best region with which the writer is acquainted for observing the contact is on the coast of Monterey county, where the crystalline axis of the Santa Lucia leaves the shoreline at a small angle, and is gradually replaced southward by the pre-Cretaceous series without any break in the topography. Numerous deep canyons descend to the ocean, cutting across both the crystalline schists and the younger series, giving fairly good exposures. South of point Sur, for a distance of 25 miles along the coast, the belt of noncrystalline rocks, consisting of slate, sandstone and jasper, is quite narrow. In the vicinity of Slates Springs this series terminates downward by a coarse conglomerate nearly 1,000 feet thick and traceable for several miles. Slate forms the coastline at the springs. The strike is parallel to the coast; dip about vertical. It is followed by sandstone toward the mountains, and that by the thoroughly cemented conglomerate. The latter is formed of smoothly rounded granitic bowlders of all sizes, embedded in a sand of the same composition. The matrix is so hardened and metamorphosed as to closely simulate a crystalline mass. Most of the bowlders resemble the chlorite-granite which occurs along the western slope of the range. On the mountains north of Mill creek, and also on Vicente creek, the slightly metamorphosed sandstones of the pre-Cretaceous series were observed resting on the crystalline complex, with no intervening conglomerate.

The reason for the assertion that this noncrystalline series is older than the Cretaceous will be given later.

### *PRE-CRETACEOUS SERIES.*

*Character, Extent and Relations.*—One of the most prominent features of the Coast Range geology is a series of rocks of rather peculiar lithologic character, concerning the exact age of which little is definitely known. It has undergone intense crushing over large areas, and exhibits more or less distinctly a silicious metamorphism, which as a rule makes its separation from the more recent formations easy. The series has been variously classed by different geologists as Tertiary, Cretaceous and metamorphic Cretaceous. The comparative uniformity of the rocks of this series from its most southern exposure to the Oregon line is a most remarkable feature.

The northern limit of the series along the coast never has been determined. The writer has been informed by Mr Watts, of the State Mining Bureau, that jasper and sandstone similar to that in the vicinity of San Francisco have been observed by him in Del Norte county along the

Oregon line, and it is probable that rocks of the same age are to be found in the Coast ranges of Oregon. The existence of a pre-Cretaceous series along the main crest of the Coast ranges in Tehama county has been amply proved. A similar series is exposed in all those portions of Humboldt and Mendocino counties not covered by the Tertiary. As we follow it southward it gradually becomes less prominent on the surface, being covered to a great extent by the Cretaceous and Tertiary. The farthest point to which it can be traced southward is southern Santa Barbara county, where it disappears beneath the Cretaceous. For a clearer idea of the distribution of these rocks in the Coast ranges the reader is referred to a map published in the American Geologist for February, 1893. It will be seen that south of Clear lake the exposed areas diminish very materially. Numerous small areas, which are not indicated on the map, are scattered through the Coast Range region, and it would seem probable that, with the exception of the granitic axes, it everywhere forms the basement on which the Cretaceous was laid down.

No attempt will be made to define its boundaries in the Klamath Mountain region, where rocks varying in age from the Jura-Trias to the Devonian are known to exist; nor is it known in what relation the pre-Cretaceous series of the central Coast ranges stands to the older rocks of Trinity and Shasta counties, but it is believed that much of it represents the last sediments deposited before the great upheaval terminating the Jurassic. The metamorphism gradually increases toward the north, where the rocks become fully crystalline.

*Lithology of the noncrystalline Portion of the Series*—Jasper or Phthanite.—The jaspers or phthanites, as they have been termed by Dr Becker, are the most characteristic rocks of the series. They are widely distributed, though their total area bears a small proportion to the whole. They form so striking a feature that they have been particularly referred to by all the earlier geologists. The beds consist of thin bands of silica, which under the miscroscope is shown to be a mixture of amorphous and crystalline silica in varying proportions, together with iron oxides and aluminous matter. The bands range in thickness from half an inch up to several inches, with thin partings of argillaceous matter. As a general thing the bands are more or less crumples and filled with minute interlacing quartz veins.

Blake* refers to these jaspers as much contorted and crumpled, ribbon-like and filled with veinlets of white quartz. He supposed that they had resulted from the metamorphism of sandstone and shale by igneous action.

* Pacific Railroad Survey, vol. v, p. 155.

J. S. Newberry * says of the jasper about San Francisco:

"Veins of white quartz, generally small, traverse it in every direction, and where it is weathered it is often peculiarly cellular, ragged and rough. Where stratified the laminæ which it exhibits are twisted and contorted in all possible directions, and, whatever is the history of the material of which it is composed, whether it is thrown up from below or, as is more probable, it is a metamorphosed form of the associated rocks, it is evident that it has been subject to a high degree of heat."

Whitney † refers to the jaspers as silicified shales.

They were first thoroughly studied by Dr Becker,‡ who speaks of them as "shales silicified to chert-like masses, of green, brown, red or black colors, intersected by innumerable veins of silica." He says further:

"Under the microscope the most highly indurated specimens are found to contain fossils."

All observers seem to have noted the wavy, thin bedded structure and the network of quartz veins. These characters are widespread, being exhibited by the jasperoid rocks of the pre-Cretaceous series through their whole extent in the Coast ranges. In the opinion of the writer, these peculiar jaspers are confined to that series and form one of the means by which it can be detected. The most striking outcrops with which the writer is familiar occur in Red Rock canyon, eastern Santa Barbara county, where an immense pinnacle of red jasper rises with precipitous faces 200 to 300 feet. At nearly every locality where the pre-Cretaceous series of rocks outcrops, from this point northward, the jasper is to be seen. Red jasper of a similar character has been observed in Trinity county and near the coast on the Oregon line.

A number of slides were prepared from specimens collected from different sections of the Coast ranges. A study of these showed the existence of such a remarkable uniformity that one description will answer for the essential features of them all. They consist of a minutely granular aggregate of crystalline quartz, with varying proportions of isotropic silica. The different colors are due to a varying amount of iron oxide, the red varieties being so impregnated with it as to be almost opaque. Minutely circular or elliptical areas, sometimes a millimeter in diameter, but generally less, are scattered through the rock, sometimes forming as much as a fifth of the total mass. By transmitted light these spots are distinguished by being clearer than the rest of the rock, while in polarized light they show a radial or granular aggregate of crystalline quartz which in optical properties resembles chalcedony. In only one slide was there noticed any traces of structure in these circular bodies.

* Pacific Railroad Survey, vol. vi, p. 12.

† General Geology of California, p. 66.

‡ Geology of Quicksilver Deposits of the Pacific Slope, p. 106.

There is no doubt that they all belonged originally to silicious organisms of the radiolarian type, but that in the various metamorphic actions to which the rocks have been subjected the structure has been nearly if not quite obliterated. This character was first noted by Dr Becker,* and on the authority of Professor Leidy was considered of organic origin. The silica which forms the mass of the rock belongs more to a chalcedonic variety than to quartz, for it seldom polarizes brightly. The minute intersecting veinlets are also partly of the same character; the larger ones, however, seem to consist of normal quartz.

The lessons to be drawn from these facts are that the jasper in its essential character is not a metamorphic rock, and that it was formed of silicious sediments resulting in great measure from organic life, as has been demonstrated to be the case with similar rocks in other parts of the world. In the Manual of Paleontology,† by Nicholson and Lydekker, the Radiolaria and the part played by them in the formation of silicious rocks is discussed. The following quotation will illustrate:

> "Many of the Jurassic Radiolaria occur in jasper, flint or chert. Jaspers with Radiolaria are considered by Haeckel as of the nature of true 'silicified deep-sea Radiolarian ooze.'"

The entire freedom of the jaspers from any fragmental material deposited in the ordinary way near a shore would indicate their formation in deep or at least quiet waters. The very rare occurrence, however, of limestone in this series and the abundance of sandstone would seem to indicate the absence of deep-sea conditions during the deposition of the greater portion.

No one has yet worked out the stratigraphic position of the jasper beds in the series, and ascertained if they are distributed through it or confined to a single horizon. The wide occurrence of the jasper beds may not, perhaps, result so much from any great extent vertically as from the extremely crushed and broken condition of the series as a whole. As a result of this condition, strata of the same or nearly the same horizon might be exposed in many places. So far as the writer is aware, jaspery beds are absent from the recognized Cretaceous, but in the Miocene there again appear flinty beds of probably the same origin, but wholly free from the secondary silicification so characteristic of the earlier ones.

Sandstone.—Dr Becker has described the sandstones of this series, and nothing much that is new can be added. He emphasizes their arkose character and the evident derivation from granitic rocks, which he conceives underlie the greater part of the Coast ranges. The sandstone is by far the most extensive portion of the series. It presents a very uni-

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*Quicksilver Deposits of the Pacific Slope, p. 108.
† Vol. i, pp. 147, 148.

form character, specimens from different portions of the Coast ranges differing more in degree of metamorphism than in any original character. Quartz is always present in more or less angular grains, but in all the sections examined it is excelled in quantity by the feldspar. The feldspar consists partly of twinned plagioclase and partly of orthoclase, the latter more abundant. Much of it, especially the smaller grains, is completely clouded. Hornblende was observed in only one specimen, that from Del Norte county. Mica is occasionally present in irregular brown scales, in part seeming to be of clastic origin and in part certainly as a secondary mineral developed in the metamorphism. Small quantities of iron oxide and other almost opaque minerals are present. The absence of hornblende from the sandstones of the central Coast ranges is strong evidence in support of the view of their having been derived from the preëxisting granite axis in that region, the rare occurrence of hornblende in the granite of the Coast ranges (excepting that of the Klamath mountains) being in such marked contrast to that of the Sierra Nevada. The prevailing color on a fresh surface is a dark gray; on weathering it turns yellowish. The somewhat angular form of the grains is a noticeable feature, one which bears out the view of the direct derivation of the components from the crystalline rocks without a great deal of attrition. The sandstones have been fractured and penetrated by silicious waters in a somewhat less degree than the jaspers. A massive, thick bedded character is to be noted in many places. These portions, though fractured, do not show the effects of crushing, as do the shales and thin bedded jaspers.

Shale and Slate.—Shale and slate form, next to sandstone, the most extensive portion of the series. Real slate, however, is not common on account of the peculiar conditions which have existed. There are but few areas of any extent where the pre-Cretaceous rocks appear in which there is not to be observed the effects of extreme dynamic action as a crushing force. These effects are particularly noticeable in the argillaceous portion. So far as observed, the main cleavage is parallel to the sedimentation. In areas where the pressure has been exerted normal to the plane of sedimentation a fine cleavable slate has been produced, but generally the strike and dip are so variable that a uniform direction of pressure would seldom be normal to the bedding. As a result, there are two or more intersecting lines of cleavage, so that the rock breaks up into sharply angular fragments. The action of numerous eruptive masses as well as faulting have also had a very important influence in destroying the regular cleavage. Where the distortion has been greatest the result is a clay, which has acted as a sort of cushion for the less yielding rocks. There are considerable areas of this series in the Coast ranges

where but little distortion and metamorphism have been felt, and the argillaceous rocks still retain their soft, shaly character.

*The semicrystalline Portion of the Series.*—As we follow the pre-Cretaceous series toward the north it gradually assumes a considerable degree of metamorphism, both chemical and dynamic. According to the reports of various observers, the series forms the basal rocks exposed in Mendocino, Humboldt and western Del Norte counties. The late W. A. Goodyear, for a number of years a member of the Geological Survey of California, under Whitney, though considering these rocks as metamorphosed Cretaceous, noted very distinctly the gradual increase of metamorphism toward the higher portions of the northern Coast ranges. In view of the utter lack of any attempt on his part to demonstrate a particular theory, the following quotation has the highest significance: *

"It appears to be a remarkable fact, which I noticed not simply on this Eel river trip, but also elsewhere in our travels, that as we approach the higher mountainous regions northwest of Clear lake the general lithological character of the rocks appears to undergo a gradual change. The country appears to be almost everywhere metamorphic, and, so far as I have seen, the degree of metamorphism is often higher than otherwise, though in some places every stage may be found from entirely unaltered to the most highly altered and crystalline rock, but the character of the change is different. The quantities of serpentine and of the jaspery and semi-jaspery rocks of the Coast range farther southeast rapidly diminish, while micaceous and hornblendic schists and argillaceous slates, etcetera, are oftener seen. In short, the rocks seem to belong to the classes which are generally more crystalline in their texture. The quantity of lime in the rocks also appears to diminish. White solid quartz occurs far more frequently. Even the granular metamorphic sandstones have a different look.

"At one point near Upper lake I noticed even the entirely unaltered sandstone so filled with scales of mica as to render its structure thoroughly schistose. Indeed, appearances everywhere are such as to suggest at once the question whether on going northwest from Clear lake, among the higher mountains, there is not a gradual and more or less complete change in the general lithologic character of the rocks, from that which is peculiar to the Coast range farther southeast to one which is more similar to that of the rocks on the western slope of the Sierra."

The writer's field-work has extended along the crest and eastern slope of the Coast ranges from Napa county north to Siskiyou county. The gradual increase in metamorphism is very plainly to be seen, together with a considerable change in the lithologic character of the rocks. Jasper, slate, hydromicaceous and chloritic schists occur in many places on the eastern slope of the Yallo Bally mountains, and, according to Mr Goodyear, the rocks on the western slope are much the same. The summit of the range consists of an exceedingly contorted and silicified

* Tenth Report of State Mineralogist of California, p. 316.

mica-schist, in places varying to green talcose slate, often semicrystalline. These schistose rocks are crumpled in fine lines and curves as if some mighty force had been exerted upon them parallel to the planes of stratification. On the eastern slope of the range the talcose or hydromicaceous schists were traced north to Bully Choop, in southwestern Shasta county. J. S. Diller, as well as the writer, obtained fossils from an outcrop of gray limestone near the base of the range in Tehama county. Mr. Diller has reported them to be Carboniferous. A limestone bed quite similar is reported as far south as Toms creek. The limestone and associated slates ought not to be confounded with the characteristic rocks of the pre-Cretaceous series, in which limestone is very rare. The rocks forming the summit of the Yallo Bally mountains to the west of the Carboniferous are undoubtedly younger—perhaps middle or lower Mesozoic. They are certainly not Cretaceous; J. S. Diller has given ample proof of this.

From Lake county northward the jasper, slate and sandstone become gradually more indurated, the sandstone turning to quartzite and the argillaceous rocks to mica and chloritic schists, the jasper being a silicious rock retaining much of its original character. The original lithologic character of the series undoubtedly gradually changes toward the higher portion of the Klamath mountains, and it is quite probable that the horizons represented in the middle Coast ranges do not appear there. As the disturbance and elevation in the Coast range axis culminated in the Klamath mountains, it is but natural to expect that successively younger strata would be exposed on the flanks.

### *ERUPTIVES.*

*General Characteristics.*—The pre-Cretaceous series contains a great number and variety of crystalline masses intruded prior to the deposition of the Cretaceous. These are exclusive of the serpentine, which is considered to be of Cretaceous age.

The glaucophane-schists are among the most striking of those rocks which are supposed in part to have been derived from ancient eruptives. They have been noted by the writer from Santa Barbara county north to Lake county, and undoubtedly extend much farther. The glaucophane does not always form the chief constituent of these schists, but is associated with actinolite, hornblende, mica, chlorite, etcetera. Some geologists have considered these schists to be of sedimentary origin.* It is believed, however, that thorough study will prove that many of

*Since this was prepared for publication F. Leslie Ransome, Fellow in the University of California, has demonstrated that the glaucophane-schists of Angel island are the product of contact metamorphism.

these occurrences have resulted from the metamorphism of a crystalline rock. One strong argument in favor of its eruptive origin is the marked contrast between the small dike-like masses and the enclosing rock, which is often only slightly metamorphosed. In the San Onofre range, in San Diego county, is a breccia containing many fragments of glaucophane-schist, among which can be noted transitions to a massive crystalline rock.

*Alteration an Obstacle to Identification.*—The great numbers of intrusives in the pre-Cretaceous series, both dikes and surface flows, have been studied only in places. They are generally much decomposed, so much so that it is often difficult in the field to distinguish them from the sedimentary rocks. In many cases the original minerals have entirely disappeared, and their places have been taken by secondary ones. They have, of course, participated in the distortion to which the pre-Cretaceous series has been subjected. The most of them certainly antedate the Cretaceous.

### *ROCKS OF THE KLAMATH MOUNTAINS.*

*Characteristics and Relation to Rocks of other Localities.*—All the evidence thus far gathered tends to show that no sharp lines can be drawn on lithologic grounds between the older rocks of the central Coast ranges and those ranges included under the term Klamath mountains. Stratigraphically those of the Klamath mountains are older. The silicious metamorphism of the central Coast ranges has been noted in many places in Trinity county and southern Siskiyou. There was also noted as accompanying it a disturbed and broken condition of the strata. These features were not prominent east of the north and south line of the Trinity mountains.

In a general way there might be two divisions made of the Klamath mountains—the eastern portion, in which the rocks resemble those of the Sierra Nevada and are comparatively regular in strike and dip, and the western, in which the rocks resemble those of the Coast ranges and have been mashed together rather than folded.

*The Nonconformity beneath the Knoxville.*—The nonconformity of the rocks of the Klamath mountains beneath the Shasta-Chico series is too well substantiated by the work of Mr Diller to need any further proofs. He says: *

"The same unconformity extends southwestward by way of Redding, Horsetown and Ono along the western side of the Sacramento valley into Tehama county, California."

That unconformity traced by Mr Diller, with all its marked features,

* Bull. Geol. Soc. Am., vol. iv, p. 221.

south to the fortieth parallel, the limit of his field, it is the object of the writer to demonstrate can be traced through the Coast ranges as far south as Santa Barbara county.

## Orographic Movement.

### *ITS EXTENT AND TIME OF OCCURRENCE.*

The upheaval which caused the deformation and metamorphism of the rocks of the Klamath mountains, there is good evidence to affirm, extended south as far as the rocks under discussion can be traced. The evidence adduced by Mr Goodyear of the gradual decrease of metamorphism southward should have great weight. His views, as expressed in the coloring of the preliminary geological map published by the California State Mining Bureau, show that he considered the rocks of the Yallo Bally mountains as more metamorphosed portions of the Cretaceous. In believing them to be Cretaceous he simply followed the prevailing views as to the "metamorphic series." In all his references to the slate, sandstone and jasper of the northern Coast ranges he conveys the idea that they all belong to one series. Time and again he also remarks upon the extreme deformation to which they have been subjected, as often shown by the complete obliteration of the stratification. This latter feature has been remarked by nearly all the workers in California geology.

### *PHYSICAL MANIFESTATIONS.*

This remarkable convulsion had the effect of mashing the strata together and forming sharp folds. The character of the deformation is one of the most striking features of the pre-Cretaceous series as a whole, and is one of the many means by which it can very often be distinguished from the overlying Cretaceous. Although in the majority of cases the actual contact of the recognized Cretaceous with the older rocks cannot be found, yet the crushed and broken condition of the latter is in most marked contrast to the comparatively regular stratification of the Cretaceous, and is good proof of a physical break. The following quotation from Becker* is interesting as bearing on this point, and shows how different were the conditions of mountain-making at the time of this upheaval from those of any subsequent period:

> "The metamorphic rocks have been dislocated in the most violent manner; indeed, the greater part of the mass was crushed at the time of the metamorphism to a small rubble. This is the case throughout the entire quicksilver belt, and renders it utterly impossible to plot any sections of the metamorphic strata."

*Quicksilver Deposits of the Pacific Slope, p. 293.

These conditions are undoubtedly due in large part to the lack of a fused upwelling magma along the line of weakness. Lateral compression must have been the chief cause of this pre-Cretaceous upheaval.

### *CORRELATION OF THE UPHEAVAL.*

The recent work of the United States Geological Survey has demonstrated the Mesozoic age of the greater part of the granite of the Sierra Nevada. It seems to be the opinion of a number of paleontologists, among whom are Professor Hyatt and J. P. Smith, that the youngest of the sedimentary rocks involved in this upheaval belong to the Jurassic rather than to the Cretaceous, a fact for which the writer has contended on stratigraphic and lithologic grounds. This revolution in the Sierra region can be traced into the Klamath mountains, where the granite of the Trinity mountains is intrusive in slates, a part of which Mr Diller considers as belonging to the Jura-Trias. The effects of this stupendous revolution in the region of the Sierra Nevada and of the Klamath mountains, accompanied by the upwelling of a great granitic magma, must have been felt to a considerable distance. At the same time the pre-Cretaceous series of the Coast ranges experienced its first elevation from beneath the ocean. Toward the south the axes of uplift corresponded in part to the ancient granite ridges against which this series was deposited and in part were independent of them. Between the Trinity mountains and San Francisco bay the elevation and enormous erosion which has taken place since has brought to light no central axis. A series of ranges was formed with a trend slightly more to the west than the course of the elevation as a whole. All evidence at hand points to the fact of the first upheaval of the pre-Cretaceous series of the central and southern Coast ranges as being coeval with that of the Yallo Bally, Trinity and plexus of mountains to the northwest, which closed the Jurassic. In the Coast ranges proper there was no breaking and tilting back of the sedimentary series by a fused granite core. The movement was marked by a folding and crushing together of the strata to form a series of more or less parallel elevations.

### *METAMORPHISM INCIDENT TO THE MOVEMENT.*

*Dynamic Metamorphism.*—During the period of elevation and deformation the dynamic metamorphism took place, being more intense toward the north. Through the Coast ranges south of the Klamath mountains this metamorphism was not great, though the rocks are referred to in geologic literature as "metamorphic." With local exceptions, they are uncrystalline, and only rarely have secondary minerals been formed.

*Chemical Metamorphism.*—Probably following the upheaval, and during

the time interval which intervened before the deposition of the lowest Cretaceous, occurred the peculiar chemical metamorphism which is apparent in rocks of this series wherever they outcrop. The silicious waters, the circulation and mineralization of which was due to the heat and chemical action existing during the mountain-making movements, permeated the rocks through the innumerable fissures which the strain had produced. This silicification was more pronounced in those strata sufficiently consolidated to be fractured; less so in the yielding argillaceous ones. As was shown in the sections of jasper, the numberless minute veins are largely formed of chalcedonic silica, and they were probably filled by infiltration from the jasper itself. The large veins in the jasper and all those in the other rocks have been filled from below in the manner described. With local exceptions, this silicification can be detected over the whole area occupied by this series from the most southerly outcrop to the northern boundary of the state. As the Cretaceous is free from this chemical metamorphism, even on the slopes of the Yallo Bally mountains, where it is the most pronounced in the older rocks, we have the strongest proof for its having taken place prior to the deposition of the Cretaceous. Moreover, this silicification of rocks known to be older than the Cretaceous in the Klamath mountains is traceable without any break, appearing only in less degree, through the whole extent of the Coast ranges. The lower Cretaceous, wherever it appears in the central and southern Coast ranges, is wholly free from any regional metamorphism, showing much the same character as on the eastern slope of the Yallo Bally mountains. Everywhere the deformation and metamorphism was strongly marked when the Cretaceous began to be deposited.

## Correlation of the Quartz-veins.

It seems probable that the great quartz veins of the Sierra Nevada date from this same time; that is, posterior to the later granitic irruption. In the Sierra Nevada the regularity and size of the veins is due, in part at least, to the comparatively uniform strike and dip of the strata, while in the Coast ranges the extreme irregularity of the stratification made such quartz deposits impossible. Gold-bearing quartz-veins, small and irregular, are to be found from Santa Barbara county north to the rich gold-bearing areas of Shasta county. Small veins have been prospected for gold in the canyon of the Cuyama river, in northern Santa Barbara county. In Monterey county, in rocks of the same age, are located the deposits of the Cruikshank mining district. Here are rich but bunchy gold-bearing quartz-veins in crushed sandstone and shale. In many other portions of this county, as well as in San Luis Obispo

county, gold is found in quartz-veins in the pre-Cretaceous series. It has been found in small amount near San Francisco and at numerous other points through the central Coast ranges. Over a large part of the Coast ranges the chemical action resulting in the deposition of silica was less intense than in the Sierra Nevada, but there is no evidence which would place the formation of the quartz-veins of the two ranges at different epochs. With local exceptions, there is no evidence of any metamorphism, either chemical or dynamic, during any portion of Cretaceous or more recent times.

## Age of the Sedimentary Series.

### *PALEONTOLOGIC EVIDENCE.*

The age of the series is a question concerning which there is very little evidence beyond the fact that it is pre-Cretaceous. The age of a portion at least, as indicated by the fossils which have been found, is not greater than the Jurassic. On the north it is not sharply defined from the Carboniferous and early Mesozoic. The past summer the writer found poorly preserved specimens of *Inoceramus* in the slates overlying the basal conglomerate before referred to as occurring on the coast of Monterey county. These fossils were examined by Mr Stanton and Professor Hyatt and pronounced not younger than the Cretaceous nor older than the Jurassic. It is very probable that the *Inoceramus* reported by Professor Whitney from Alcatraz island, although better preserved, is fully as indefinite in its time indication. The rocks of that island are not separable lithologically from the pre-Cretaceous series north and south.

That less than a half dozen poorly preserved specimens should have been discovered up to the present time, notwithstanding all the search that has been made, is a very remarkable fact. Over much of the region the metamorphism has not been sufficient to destroy the remains of life if it ever existed, but it would seem probable that the extreme deformation to which a large part of the area has been subjected is one of the chief causes of the obliteration of fossils. The species found are rather indeterminate in character, and while paleontologists may differ as to whether they indicate Jurassic or Cretaceous age, stratigraphic and lithologic considerations place the strata containing them in the Jurassic.

It seems to be quite certain that wherever the Lower Cretaceous occurs it has been found to be well supplied with the remains of molluscan life. On the other hand, that very series of rocks which on lithologic and stratigraphic considerations the writer would refer to an earlier age have so far proved almost barren of life. It would be strange if this far-reaching condition should not have an important significance. It is

becoming more apparent every day that the determinations of the age of strata based merely on a scanty fauna are in many cases very uncertain.

*STRATIGRAPHIC AND LITHOLOGIC EVIDENCE.*

Although it is a general principle laid down in geology that correlations based on stratigraphy and lithology in regions in which the strata cannot be traced by continuous outcrop are to be accepted with caution, yet the writer believes that in a study of the Coast ranges, where fossils are rare in the older rocks, these determinations, properly used, are of the highest importance. The fact that rocks of this series are marked everywhere by constant lithologic features and exhibit the same kind of metamorphism as the rocks of the Klamath mountains is sufficient to enable us to separate them from the Cretaceous. The metamorphism, though not always pronounced, is distinct enough, when taken in connection with the lithologic features, to enable the lines to be drawn. The validity of this demonstration of course rests upon the fact of the absence of metamorphism, both dynamic and chemical, from all portions of the known Cretaceous. The writer has examined portions of nearly all the areas of Cretaceous in the central and southern Coast ranges, but has never yet encountered any jasperoid rocks in that formation.

The rocks of the pre-Cretaceous series generally show a character peculiar to the Coast ranges, yet in places portions of the series resemble the metamorphic rocks of the Sierra Nevada. In the northern counties there are many outcrops of a finely cleavable slate. In Monterey county a large area of slates extends southeast from Salmon creek for several miles. The slates are black, cleave as finely as those along the Mother lode in the gold belt and in manner of decay very closely resemble them. The extraordinary development of sandstone and jasper are perhaps the striking lithologic features. The abundance of sandstone would indicate shallow waters not far removed from land areas. It seems quite probable that the basement complex of crystalline schists and granite stretching from point Reyes to the Peninsula range was in early Mesozoic times far more elevated than at present. Toward the middle Mesozoic a sinking began, continuing through the Jurassic, but insufficient to cover the granite ridge on the flanks of which the pre-Cretaceous rocks were laid down. This ancient granite range now appears, where not elevated by recent movements, as a sunken range or one worn down to baselevel.

The almost entire absence of limestone in the pre-Cretaceous series is a remarkable fact. It is one of the evidences of shallow water near to land areas. As we go north into the Klamath mountain region in Trinity and Shasta counties the limestone becomes abundant. In that region there is a less predominance of sandstone. These facts all point

to the existence of an extensive land area in the region of the central Coast ranges during early Mesozoic times, one which perhaps extended as far west as the Farralone islands, which consist of granite and belong to the continental plateau. To the southeast it was likely continuous with the Peninsula range of Southern California.

## Cretaceous of the Coast Ranges.

### *DISTRIBUTION.*

The Cretaceous is widely distributed in the Coast ranges. It occurs on the eastern slope nearly the whole length of the San Joaquin and Sacramento valleys. Within the Coast ranges it occurs more extensively south than north of San Francisco. The past season the writer discovered that a large portion of the high mountains in northern Ventura and Santa Barbara counties consists of Cretaceous and Eocene strata, showing in places an enormous thickness, comparable to that found by Mr Diller in Tehama county. As far as the scanty paleontologic evidence goes, the greater part of this series appears to belong to the Upper Cretaceous, extending upward into the Téjon or Eocene, with a comparatively small development of distinctly Lower Cretaceous. In northern Ventura county there is an exposed width across the strike of the Chico-Téjon series of twelve miles, but the dip is so irregular that the thickness could not be determined. In Santa Barbara canyon, which cuts somewhat diagonally across the stike of the rocks of the same series, they show an almost uniform dip for a distance of ten miles. The dip is to the southwest at an angle of about forty-five degrees, and the estimated thickness at least twenty-five thousand feet. In San Luis Obispo county the Chico, the Téjon not having yet been recognized, consists largely of sandstone, and is confined to the line of the Santa Lucia mountains, occurring along the eastern slope at least as far north as central Monterey county. The Chico-Téjon is also found in San Benito county on the western side of the Monte Diablo range. On the eastern side of the range in Walton canyon there is an exposed thickness of at least twenty thousand feet. The Chico is known to occur on the coast north of San Francisco and in some of the interior valleys.

H. W. Turner several years ago detected the Lower Cretaceous in the Santa Lucia range near the town of San Luis Obispo. The writer has traced the black shale of this formation along the summit of the range for some miles. Numerous specimens of *Aucella* were found in it near the Old Padre mine west of Santa Margarita; also on Toro creek and at an intervening locality, and on Pine mountain near San Simeon. This formation, consisting almost wholly of black shale, begins a little southeast of the new railroad tunnel, and extending along the eastern side of

the range for several miles, crosses it on the head of Morro creek, and on Toro creek appears enclosed between two high serpentine ridges which form the crests of the range. It was found again on Pine mountain on the summit of the range back of San Simeon. Here it is capped by a body of liparite. Outcrops of somewhat limited extent of supposed Lower Cretaceous shales were seen a few miles west of Santa Ynez, in Red Rock canyon, and Cachuma canyon, Santa Barbara county.

### *SEPARATION FROM THE PRE-CRETACEOUS BY AN UNCONFORMITY.*

The unconformity of the Lower Cretaceous on the older rocks of the southern Coast ranges is evident, though no good contacts were observed. Excellent contacts of the Upper Cretaceous with the pre-Cretaceous were seen in a number of places and will be described later. The small area of *Aucella*-bearing Cretaceous on the summit of Pine mountain overlies rocks of the pre-Cretaceous series. The Cretaceous consists of shale with some thin strata of sandstone dipping irregularly into the mountain. As the mountain is descended this is seen to be replaced by crushed and distorted rocks of the older series, consisting of shale, sandstone and jasper, with an apparently vertical dip. The area of *Aucella*-bearing rocks farther south was inclosed in serpentine in such a manner that the contact with the older rocks was not seen. The sharp contrast, however, between these soft shales and sandstone, with comparatively regular strike and dip, and the older distorted series is very marked. Areas of undoubtedly Lower Cretaceous age occur in Cachuma canyon and Red Rock canyon in such relation to the underlying series that there can be not the slightest doubt as to an unconformity.

### *ABSENCE OF REGIONAL METAMORPHISM.*

There is an entire lack of regional metamorphism in all the known Cretaceous of the state. As far as the amount of consolidation and hardening is concerned, both upper and lower divisions present much the same character in the southern Coast ranges as in Tehama and Shasta counties. There is an absence also of the great crushing exhibited by the older rocks. Although in some places much disturbed and folded, the stratification is generally very distinct. The regularity of the bedding of the Upper Cretaceous, when found resting on the pre-Cretaceous series, is in very marked contrast to the irregular, wavy and often almost indistinguishable bedding of the latter.

### *LITHOLOGIC CHARACTER.*

The lithologic character of the Lower Cretaceous in the southern Coast ranges is much the same as farther north. There is the same excess of soft, dark shales, with thin strata of sandstone and calcareous nodules

The Chico-Téjon consists to a great extent of coarse sandstone, with a lesser amount of shale and conglomerate.

*RELATION OF THE CHICO TO LOWER CRETACEOUS AND PRE-CRETACEOUS.*

North of the fortieth parallel Mr Diller has found no break, physical or paleontologic, in the whole series of Cretaceous sediments. While he finds the lower portion of the series somewhat more crumpled, no unconformity appears to exist. Whether we accept fully his conclusions or reject them for other portions of the Coast ranges, it is very evident that there were no great disturbances of a character to metamorphose the lower portion. As to the hardening and solidification, there is very little difference between the extremes of the series. The work of the writer in the Coast ranges has led him to believe that approximately similar conditions existed during the deposition of the Cretaceous the whole length of the state; that there was a physical break, which is more or less prominent in different localities.

Along the trail from the Cachuma canyon across the San Rafael mountains to the head of the Manzana a very thick section of the Cretaceous is exposed. These beds rest at a steep angle against serpentine, jasper, sandstone and shale of the older series. The base of the Cretaceous is a black shale filled with calcareous nodules. As exposed in a canyon leading down to the Manzana the Cretaceous dips to the north at an average angle of 45°, having a thickness of 8,000 or 10,000 feet. An ammonite was found here, but in such a poor state of preservation that the species could not be determined. At a distance of three miles down the canyon the shales and sandstones are replaced by very extensive conglomerates, with an apparent dip of 30°. The conglomerate is several thousand feet thick. It is quite probable from what was observed in the northern part of the county that this conglomerate is a part of the Chico-Téjon. It would seem highly probable that future investigations will prove the existence of the Lower Cretaceous in this region. The present evidence favors the view of a break in the series. In the southern Coast ranges the direct superposition of the Upper on the Lower Cretaceous has not been observed, either one or the other of the divisions being absent.

In the canyon of the Cuyamas the unconformity between the Cretaceous, probably the upper division, and the pre-Cretaceous series is most plainly shown. The deepest portion of the canyon is cut through a series of crushed sandstones and shales, containing small quartz-veins, jasper and dark green, fine grained eruptives. On this series the Cretaceous shale and sandstone was seen, resting at an angle of about 40°, wholly unaltered and with regular bedding lines. Now, since the rocks which have been referred to the pre-Cretaceous series have been found nearly continuous from the Klamath mountains south to this point, maintain-

ing very much the same lithologic character, and inasmuch as the lowest Cretaceous, when it occurs, also rests unconformably on the same series, we have the strongest evidence that this unconformity, so unequivocally shown, is the same which has been found to exist in the northern part of California. If it is not, then there must exist a comparatively local disturbance and metamorphism within the Cretaceous exactly simulating that at the base of the Cretaceous farther north, but the character of the lowest Cretaceous found in several localities in this region utterly forbids this supposition. Let it be understood, however, that this does not disprove a disturbance merely, during the Cretaceous, which the writer holds is demonstrable.

### *PROBABLE EPOCH OF THE SERPENTINE INTRUSION AND ITS EFFECT UPON THE CRETACEOUS.*

Mr Diller, in a recent publication,* says, with reference to the serpentine, that it is undoubtedly an altered eruptive and younger than the Knoxville portion of the Shasta-Chico series. With this view the writer is in complete accord. Instances of contact metamorphism were given in a former paper. There are no recorded observations of the serpentine having been found eruptive in the Chico. About Clear lake is a large area of sandstone of this age, and while serpentine occurs in the older rocks near by, none is present in the Chico. It will, perhaps, be argued that the Chico is generally found farther away from the axis of disturbance than the Knoxville, which is the case along the west side of the Sacramento valley; but in several places farther south the Chico was observed superimposed on the serpentine, and nowhere was it seen intruded by that eruptive. The Chico rests on serpentine in many places in the Santa Lucia range, while in other localities, particularly in the canyon of the Santa Ynez river, the serpentine is intruded in black shales of Lower Cretaceous age. Over that great extent of country in Ventura, Santa Barbara, and San Luis Obispo counties covered by the Chico-Téjon there are no traces of serpentine, while in nearly every spot where the pre-Cretaceous or Lower Cretaceous is exposed by erosion dikes of serpentine are found. This was noted in the mountains east and north of Santa Ynez, in the Santa Lucia range south of Poso, and at other points farther north.

At some period during the Cretaceous a disturbance took place, probably an elevation, extending through the whole length of the Coast ranges, and accompanied by the extrusion of peridotitic eruptives. Although in some cases the areas of these eruptives are very large, yet the metamorphism shown by the enclosing rocks is not usually very pronounced, while the tilting and fracturing of the strata did not extend far.

* Bull. Geol. Soc. Am., vol. 5, p. 441.

In places the disturbance could not have been felt to any extent, as in Tehama county, where the relations of the Shasta-Chico series have been studied so carefully by Mr Diller. In that region along the west side of the Sacramento valley where the Cretaceous is so enormously thick the Chico is found several miles from the line of intrusion of the serpentine in the Lower Cretaceous and older rocks, and the disturbance is not noticeable at that distance. Mr Diller even remarks the greater amount of disturbance exhibited by the Knoxville and the lack of it in the Chico, but accounts for it by the fact that the Upper Cretaceous does not at present appear superimposed on the Lower, but at a considerable distance, where the axial movements were not felt.* An upheaval accompanying the serpentine might account for the greater amount of sandstone in the Chico, especially toward the south.

## Tertiary of the Coast Ranges.

### *EOCENE.*

So little is yet known of the detailed geology of much of the southern Coast ranges that the relation of the Eocene to the Chico cannot be stated with certainty. Fossils from both upper and lower divisions of the series have been found in different portions of Ventura and Santa Barbara counties in an apparently conformable series of rocks, but there is no blending of the faunas. The extent and character of the series has been already described.

### *MIOCENE.*

The most extensive of all the formations in the southern Coast region is the Miocene. Not only does it form the greater portion of the valleys, but in many instances isolated patches are found capping some of the highest ranges. At the close of the Miocene and before denudation began, strata of this age formed an almost universal covering, gradually decreasing in importance toward the north. It is this fact which led the earlier geologists to claim a Miocene age for the Coast ranges. It seems probable that after the beginning of the Miocene and as deposition went on a subsidence took place, for the basal portion wherever exposed shows a loose granitic sand rock, characterized in many places by the gigantic oyster, *Ostrea titan*.

The nonconformity of the Miocene on the Chico-Téjon is one of the most striking facts to be observed, notwithstanding the existence in geologic literature of many references to the conformity of these two formations. The unconformity was noted in the high ranges in northern

* Bull. Geol. Soc. Am., vol 4, p. 222.

Ventura county along the Sespe, in the valley of the Sisquoc, canyon of the Cuyamas river, south of the old mission of Santa Ynez, in the upper valley of the Salinas, and many other places. The nonconformity is so pronounced that it is surprising it should have escaped the observations of the older geologists. Dr Lawson has recently called attention to a nonconformity between the Miocene and the supposed Téjon at Carmel bay.

The Santa Ynez is the greatest single range formed wholly of Miocene strata. Lithologically, the Miocene is strongly marked, the bituminous slate series of Whitney being the most widespread and characteristic portion of the formation. These rocks have been studied recently by Dr Lawson, with the development of some interesting features. Gypsum-bearing clays are also very widely distributed.

A great elevation of the Coast ranges took place at the close of the Miocene, a fact noted by all geologists. There is no portion of the state where this has been so great as in the San Emidio range, where the Tertiary is found flanking mounts Frazer and Pinos at elevations varying from 5,000 to nearly 7,000 feet. Rocks of Miocene age cap the summit of the Monte Diablo range, in southwestern Fresno county, at an elevation of 4,000 feet. In various places in Santa Barbara county the Miocene has an elevation of from 3,000 to 4,000 feet.

### Formation of new Axes with each succeeding Elevation.

A feature of peculiar interest in this region is the fact that the Coast ranges do not consist of one main axis with a dominating range, but of a number of wholly independent ranges formed at different geologic periods. The northern portion of the Santa Lucia range, and the almost buried granite ridge connecting it with the San José range, belongs to one of the two or three earliest elevations in this region. At the pre-Cretaceous upheaval a divergent range was formed which constitutes the southern continuation of the rugged granite ranges of Monterey county. Additional movements took place along this line, while the granite ridge extending a little more easterly remained comparatively undisturbed. The Santa Ynez range seems not to have existed until post-Miocene times.

A little south of Santa Margarita, along a line from the valley to the summit of the Santa Lucia, there is crossed successively the pre-Cretaceous, the Cretaceous and the Miocene. The presence of the older rocks in the valleys or on the slopes of the range and the younger on the summit is a condition very striking in many places. Over much of what might be termed the Coast Range plateau the compressive and elevating

forces did not always act upon the already existing axes, but new ones were formed by their sides or even in divergent directions.

### The Coast Ranges Constitute a Mountain System.

Professor J. Le Conte gives the following definition of a mountain system:

"A mountain range is a single *mountain individual*, born at one time (monogenetic)—*i. e.*, the result of one, though it may be a prolonged, earth effort—as contradistinguished on the one hand from a mountain *system*, which is a family of mountain ranges born at different times (polygenetic) in the same general region, and on the other from ridges and peaks, which are subordinate parts, limbs and organs, of such a mountain individual."

It seems to the writer that this definition is applicable to the Coast ranges; that they should properly be considered a system of mountains, embracing, as they do, ranges of such different ages. This is particularly applicable to the region south of San Francisco bay. On the north there is not shown such a complexity of structure.

If the writer's views are correct, the Coast ranges are not younger than the Sierras, as has been generally supposed. According to our present information, land areas existed in this region before the Jurassic upheaval, which, in the opinion of Dr Le Conte, gave rise to the main portion of the Sierra Nevada.

### Sketch of the Geologic History of the Coast Ranges.

The age of the crystalline schists and limestone of the Coast ranges is unknown. At some period, probably during the Paleozoic or possibly earlier, an upheaval accompanied by the formation of granite took place along the axis of the Coast and Peninsula ranges, intensely metamorphosing the sedimentary strata. Owing to the fact that no trace of uncrystalline rocks older than the Jurassic has been detected along this axis, it seems justifiable to suppose that during the early Mesozoic, and perhaps later Paleozoic, the land area of the crystalline rocks was far more elevated and extensive than at present. Erosion through long intervals of geologic time would be necessary to remove all traces of the less crystalline upper rocks of this complex.

If authorities are correct, a broad sea stretched to the east over the most of the Sierra region during the period of erosion of this crystalline axis of the Coast ranges. As Mesozoic time progressed a subsidence began and continued through the Jurassic, with the deposition of what has been termed the pre-Cretaceous series. At the close of this period the great revolution in the Sierra Nevada took place, accompanied by a tilting and folding back of the strata and the formation of an enormous area of a fused granite magma. At the same time an axis of uplift was formed in the Coast ranges, being connected with the Sierra Nevada at

both ends. The elevation was accompanied by no fused central mass, but appears to have been due to a horizontal compression, resulting in a mashing together of the strata. The granite axis experienced a renewed uplift, while that portion of the Coast ranges between point Reyes and the Klamath mountains first emerged from beneath the ocean. This theory correlates in time the youngest sedimentary strata of the gold belt with the pre-Cretaceous uncrystalline series of the Coast ranges. Following the upheaval, the silicification of both ranges took place. A considerable interval of erosion is believed to have elapsed after the former event before the deposition of the lowest Cretaceous yet discovered. A subsidence continued through the Cretaceous and Eocene, except for a break, not everywhere apparent, at the time of the intrusion of the peridotitic eruptives. At the close of the Eocene another elevation took place, followed again by a depression through the Miocene, so that the latter was laid down unconformably on the Chico-Téjon. At the close of the Miocene another great elevation of the Coast Range region was experienced. Strata of that age have at present an elevation of nearly 7,000 feet in northern Ventura county. Following this other disturbances have been recorded, but will not be touched upon here.

## Conclusions.

The discussion in the previous pages, it is hoped, has demonstrated the existence of a series of uncrystalline rocks in the Coast ranges of greater age than the Cretaceous. This series underlies the Cretaceous unconformably, and rests on the worn surface of the crystalline basement complex. It is marked by peculiar and constant lithologic features, and has undergone to a greater or less degree a silicious metamorphism, distinctly marking it from the younger formations.

Attention is called to the following points, which, though less dwelt upon than the main topic, are yet of great importance:

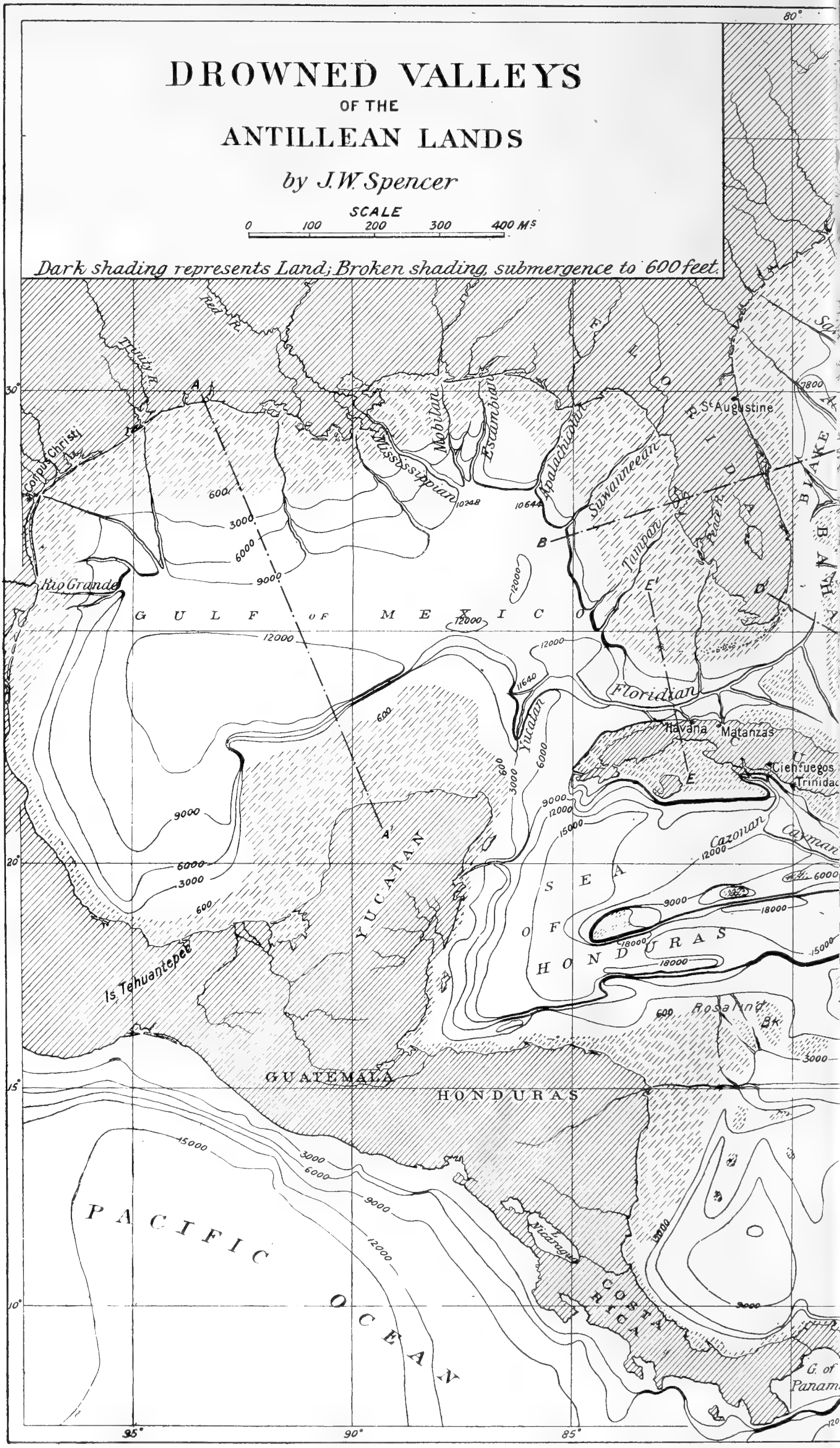
1. The seemingly great age of the crystalline basement complex; a view which, if correct, gives the Coast ranges an antiquity greater than that of a large part of the Sierra Nevada.

2. The undoubted radiolarian origin of the jaspers of the pre-Cretaceous series, and consequently the incorrectness of applying the term "metamorphic" to them.

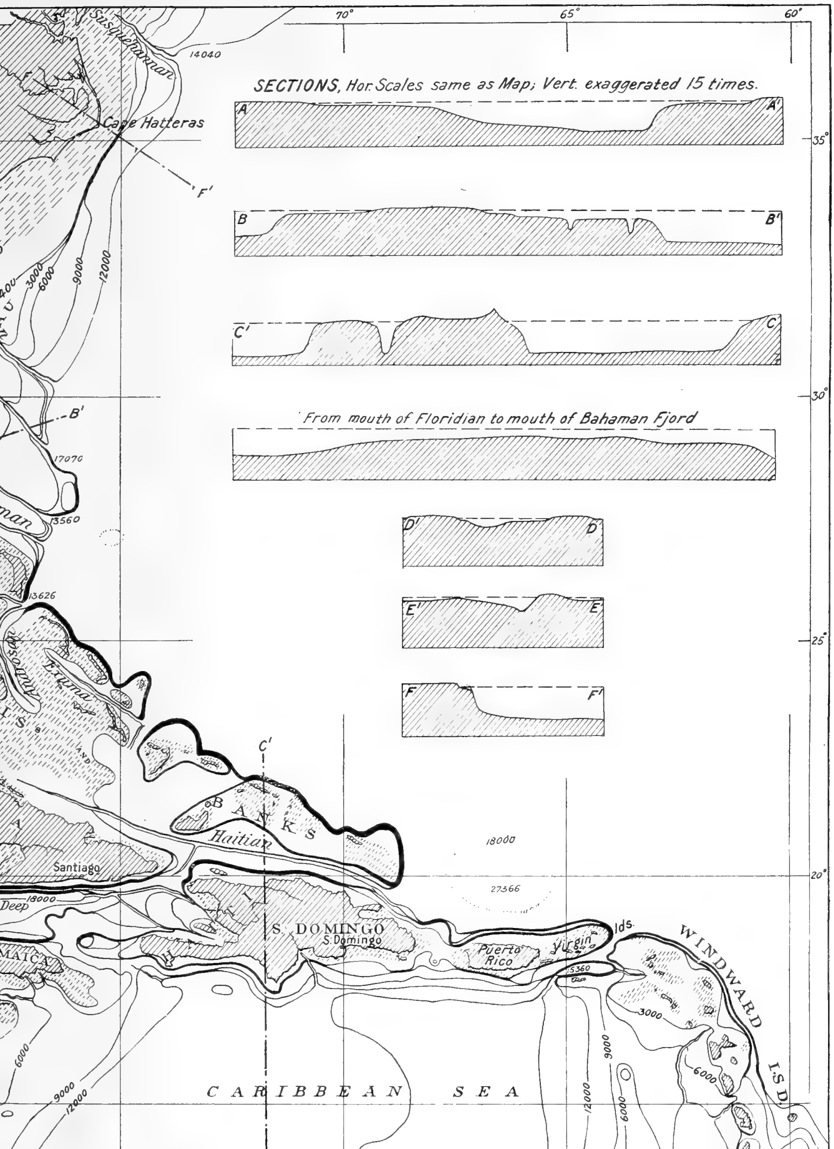
3. The probable nonconformity between the Upper and Lower Cretaceous.

4. The nonconformity between the Miocene and Chico-Téjon series.

5. The great diversity in age and complex structure of different portions of that continuous series of mountains known as the Coast ranges, making them worthy of being considered a mountain system.




Note.—The soundings are given in feet.


SECTIONS, Hor. Scales same as Map; Vert. exaggerated 15 times.
From mouth of Floridian to mouth of Bahaman Fjord
Cape Hatteras
Susquehannan
Haitian
BANKS
S. DOMINGO
S. Domingo
Santiago
Puerto Rico
Virgin Ids.
WINDWARD ISD
CARIBBEAN SEA
Barbados
Trinidad
G. of Paria
Orinoco River
L. Maracaybo
G. of Darien
Deep
Exuma
18000
27366
15000
14040
17070
13560
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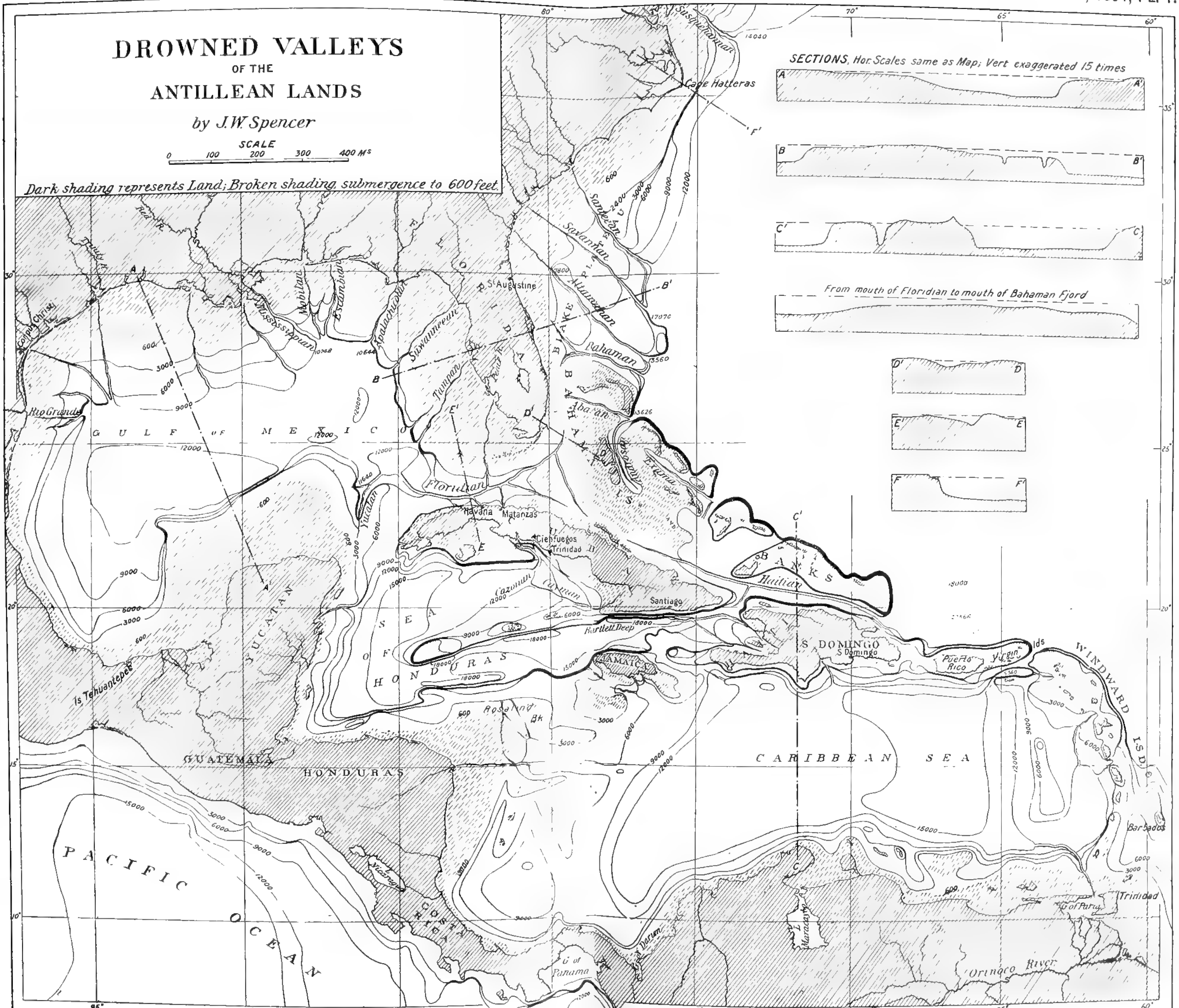
15360
12000
9000
6000
3000




NOTE.—The soundings are given in feet.

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# RECONSTRUCTION OF THE ANTILLEAN CONTINENT

BY J. W. SPENCER, A. M., PH. D., F. G. S. (L. AND A.)

(*Read before the Society August 14, 1894*)

CONTENTS



## Introduction.

For decades a vague impression has existed that some kind of continental extension formerly united the West Indies to the mainland of one or the other of the continents, or to both, and that the exclusion of the Atlantic currents and the admission of the Pacific waters into the Mexican gulf and Caribbean sea have at some time prevailed. Suggestions have been made as to the necessity of a foreign source for the mechanical sediments found in the islands which do not possess the geological quarries for the supply of such materials. Wallace* has illustrated how the Antil-

*"Island Life," by Alfred Russell Wallace, second edition, 1892, p. 263.

lean lands would be extended if the region were uniformly raised 6,000 feet. The charts of Agassiz * and others show the positions of the submerged basins. Geologists have demonstrated the great changes of level to which the Caribbean region has been subjected, but I am not aware that any geologist has hitherto † attempted to restore the topography of the submerged continent and set forth the geomorphic evidence that the drowned valleys are those of former lands, now depressed beneath the sea. The later changes of level have had far reaching effects, not only on the geographic forms, but on the climate of, perhaps, the whole Atlantic basin. These changes have also placed obstacles in the way of the distribution and development of life, or cut off and exterminated such forms as reached the Antillean lands, and have given rise to the modern distribution of Atlantic and Pacific types in the waters of the West Indies.

The present contribution is primarily based on the physical geology of the Antillean region. The phenomena of first importance are the fjords, revealed by the now numerous soundings, in connection with the land valleys of the continents and islands. Some of the valleys are now wholly submerged, even to their sources. The formation of the valleys at various elevations, depending on baselevel of erosion; the continuation of the valleys into fjords; the deformation of deserted water-margins by warping or terrestrial undulations, as recorded in the elevated terraces, beaches and other shore phenomena; the successive cycles of erosion and filling of the valleys, with the consequent unconformity of the strata, and the distribution and elevation of the later formations, with the subsequent erosion—all of these phenomena are made use of in the study set forth in this paper. Some difficulties yet remain, but to geomorphy we may hopefully look for their removal. The dynamic studies explain many biologic phenomena, and these in turn support the conclusions regarding the physical history of the continent.

This investigation is the sequence to years of inquiry into the geologic history of the Great lakes. Their depth indicates a former elevation of the continent considerably above the present altitude In looking for proofs of this greater altitude it was found that the fjords of the coast in higher latitudes are only submerged valleys. ‡ At that time the writer hesitated to admit continental changes of level greater than 3,000 feet, but with increasing knowledge of deep submerged valleys elsewhere, notably the much deeper fjords of the Antillean region, and with the find-

* "Three Cruises of the Blake," by A. Agassiz, vol. 1, 1888, figs. 56 and 57.

† An advanced notice of some of the drowned valleys appeared in Bull. Geol Soc. Am.. vol. v, 1893, p. 19, under the title of "Terrestrial Submergence Southeast of the American Continent," by the writer.

‡ "High Continental Elevation preceding the Pleistocene Period," by J. W. Spencer, Bull. Geol. Soc. Am., vol. 1, 1889, p. 65.

ing of abyssmal deposits, described by Messrs Jukes-Browne and Harrison,* and showing great changes of level in one direction, he was led to the conclusion that the great depth of the drowned valleys is not inconsistent with their fluvial origin, and this opinion has been sustained by more recent discoveries regarding their connections with existing and buried river channels of the continents and islands. It has been found that these fjords are not exceptional or scattered, but numerous and apparently connected into systems of drowned valleys. In order to extend our knowledge of the connection between the Antilles and the continent, and to obtain evidence as to when the connection existed the field-work was carried from the continent to the Greater Antilles with success beyond expectation. The later geology of that region proved that with minor modifications the terrestrial movements of the coastal plain of the continent, so admirably set forth by Mr W J McGee,† extended to the West Indies. The geographic history of Jamaica was not explained by the government geologists,‡ but their excellent data, as also those of Dr W. M. Gabb§ in San Domingo and Costa Rica and the more scanty surveys in Central America, all contain considerable material for extending generalizations based on discoveries in Cuba and the southern states (where the writer has done much work) over the whole Antillean region. These generalizations are further justified by the distribution of life in the waters of the West Indies.

## Geomorphy as exemplified in Valleys.

In northern regions the geologic broom of the Ice age swept over the hills and filled the valleys so as to greatly obscure the topography produced by meteoric agencies. Farther southward the atmospheric forces have left their record deeply engraved in the surface rocks. From the study of land features it would appear that the forms of the valleys are largely independent of the geologic undulations of the region, and that open valleys (and sometimes those closed into basins) are to a great extent the direct result of atmospheric erosion. For example, over the plains of both the coast and interior, valleys from a few rods to many miles in width may either follow the strike of the rock strata of the country or may cross their strike at any angles. In the southern Appalachians numerous valleys follow the direction of the ridges, which is generally that of the strike, and at first sight appear to occupy mountain folds.

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* "Geology of Barbadoes," Quar. Jour. Geol. Soc. London, vol. xlvii, 1891, pp. 197–250, and vol. xlviii, 1892, pp. 170–226.

† "The Lafayette Formation," 12th Ann. Rep. U. S. Geol. Survey, 1892, pp. 347–521.

‡ "Geology of Jamaica," by J. G. Sawkins, 1869.

§ "Geology of San Domingo," Trans. Am. Phil. Soc., vol. xxv, 1873. "Geology of Costa Rica," Am Jour. Sci., vol. viii, 1874, p. 388, and vol. ix, 1875, pp. 198, 320; also manuscript in archives of the U. S. Geol. Survey

This, however, is rarely the case, for if the denuded strata were restored the position of the valleys would occupy the crests of the undulations, as shown in the accompanying actual sections, where the broad valleys occupy the surfaces of both anticlinals and synclinals. Another characteristic of old valleys is that the streams flowing through them are insignificant compared with their magnitude in both depth and width. The limestones have been carried away in solution and the finer mechan-

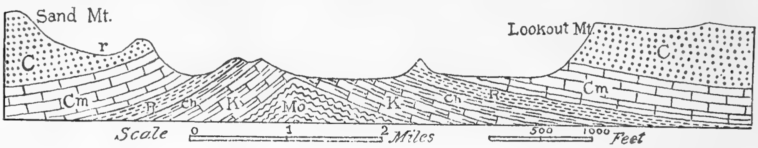


FIGURE 1.—*Section across Lookout-Wills' Valley, Alabama, at the Col.*

The incision in the tableland of Carboniferous sandstone here is about 4 miles wide and 500 feet deep. From this section, for many miles downward in both directions, the general slope of the floor of the united valley is about ten feet per mile, so that the tableland presents bold escarpments more than 1,000 feet above the lower reaches of the rivers. It is an anticlinal valley.

ical muds have been washed by the rains into the larger streams and, suspended in the waters, they have been transported out of the valleys and deposited on flood-plains or in the sea. Occasionally the streams undermine the banks and obtain extraordinary cargoes, but the principal widening agents are the rains and rills that everywhere wash away the surface and undermine the mountain sides, which action is intermittently retarded by the temporary protection of the unremoved materials of the

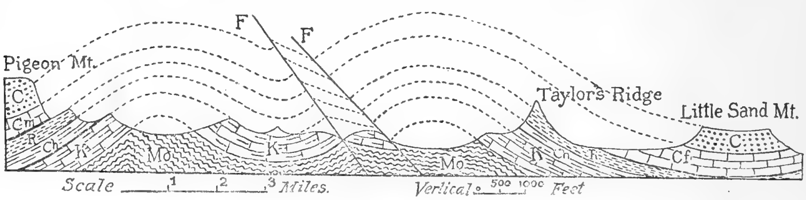


FIGURE 2.—*Section from Pigeon to Little Sand Mountain, Georgia.*

This section represents a valley of about a dozen miles in width, with the complex geologic base shown in the figure. It illustrates well how the valleys in the southern Appalachians are produced by atmospheric denudation and not by mountain folding.

landslides. While the tablelands are high, the streams are constantly deepening their channels, but when the bottoms of the ravines are reduced to the baselevel of erosion, then the streams almost cease to corrade and become geologic carriers of the surface washings of the valley.

In the recently elevated mountains of Cuba and Jamaica, as in the older Appalachian chain, the valley-making forces have overcome the physical structure, so that the valleys are more or less independent of it.

When the depressions in the rock surfaces grow wider and deeper and are kept open in their descent, one can only conclude that they represent the molding of old land surfaces by running water, no matter whether the valleys be now buried by drift or submerged beneath the sea. The geomorphic studies especially consider narrow canyons with steep walls, made by rapidly descending streams; broad valleys with commonly sloping sides, arising from rain-washes upon the hillsides when the drainage of the depression was reduced to the baselevel of erosion; the burial and the reëxcavation of the valleys; their terracing; the tilting of the land surfaces and the change of direction of the drainage or the closing of the basins into lakes. From all of these phenomena we can learn something of the geologic history of the land, while the rock formations indicate the contemporaneous history of the sea. To repeat, when we

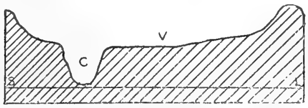


FIGURE 3.—*Cross-section (v) representing a baselevel Valley in Trinidad Mountains, Cuba.*

This district was recently elevated, and a stream at *c* is engaged in cutting back a canyon 600 feet in depth.

find systems of valleys beneath the sea, unless there are other local causes, we are led to conclude that they are the remains of land features now submerged. or, in other words, that they are evidence of former continental elevation. Under this interpretation the writer has correlated the extension of the great rivers into their fjords cut through the continental shelves along the coast, which have been made known by the numerous soundings.*

## Deformation of Land Surfaces.

The gentle but broad undulations in the earth's crust which change the relation of the land and sea and raise up barriers across valleys, so as to form basins, or divert the drainage of the land without producing crumpling and folding of the strata or other great distortions, such as in mountain uplifts, have been by Mr Gilbert denominated epeirogenic (continent-making) in contrast with orogenic (or mountain-making) movements. Such undulations are well known in the gentle rising and sinking of coasts. In the deserted beaches of the region of the Great

* See U. S. Hydrographic charts nos. 31–36, 21, 21*a*, 1007, 1411, Coast Survey charts C, D, and numerous harbor charts. The Hydrographic charts have on them many soundings taken from the British Admiralty and other surveys adjacent to the islands and coast of Florida not given on the Coast Survey charts. These British Admiralty charts have also been studied.

lakes we have been able to measure the recent deformation of the earth's crust, since the abandoned shores rise from zero to three, six or even more feet per mile toward the northeast, as shown in figure 4. The deformation is also recorded in the variable altitudes of the recent geologic formations shown in figure 5. Everywhere the movement of elevation


FIGURE 4.—*Section of the Iroquois Beach.*

A raised water-line from the head of lake Ontario for about 400 miles to south of Malone in the Adirondacks. The rise increases from an elevation of 363 feet above tide near the lake to 1,482 feet in the mountains, where the greatest deformation occurs.

appears to be greater in the mountain regions than on the plains, and it is noteworthy that the rate of depression along the coastal margins seems larger than farther inland. The epeirogenic movement does not generally deface the topographic features, although it sometimes changes the direction of the drainage and turns the valleys into basins; and in this


FIGURE 5.—*Section from South Carolina to the Mississippi, showing Deformation of the Lafayette Formation.*

At Columbia, South Carolina, the elevation of the Lafayette formation is about 800 feet above tide; in the mountains farther westward it has double that altitude, and in Arkansas less than 300 feet.

respect it has been an important factor, inclosing the Mexican, Honduras and Caribbean valleys into sea basins, though orogenic and volcanic forces also combined with the gentler terrestrial undulations in producing these abysses.

## SUBMARINE VALLEYS AND FJORDS OF THE CONTINENTAL AND ANTILLEAN REGIONS.

### *THE CONTINENTAL SHELF.*

In passing southward from New Jersey the continental shelf narrows to only about 15 miles wide off cape Hatteras (section *F F'* on accompanying map), but from that point it widens to nearly 300 miles east of Florida. Although crossed by the straits of Florida and the Gulf Stream, the plateau embraces the Bahamas, east of which its broken remains rise in banks north of Haiti and beyond it has been largely swept away. This shelf has been mostly removed by denudation, only fragments of it remaining east of the Windward islands, but off the coast of South

America it reappears, having a width of from 150 to 300 miles. An elevation of only 50 feet would turn the Bahama banks into a broad land area, and a rise of 100 to 300 feet would extend the continent to the edge of the upper shelf in front of the southern states, coastwise of which the lower terrace, or Blake plateau (so named by Professor A. Agassiz), is depressed from 2,500 to 3,500 feet. A considerable portion of this drowned plain has an average depression of 2,700 feet. East of the continental shelf (both the normal and the Blake plateau) the continental margin descends rapidly to a depth of 12,000 feet or more. Glancing at the accompanying map (section *B B′*), the drowned flats, seaward of the coastal plain of the southern states, behind which are the Appalachian mountains, and the Bahama banks in front of the plains and mountains of Cuba and Haiti, may be seen without any epeirogenic break and with only the interruptions of a few great valleys, the analogues of which occur on the continent, indicating that the whole continental shelf is a geologic unit and must be so treated. The Blake plateau may be somewhat modified by the Gulf Stream, the bottom of which in passing over the highest ridges of the straits of Florida is only about 2,100 feet below the surface, or several hundred feet above the mean depth of the water over the Blake plateau; but it is to be remembered that the force of the current, which diminishes with its depth, is very much reduced except on the more elevated surfaces of the submerged terrace. It might be noted here that in such places the current keeps the surface of the rocks free from loose deposits (Agassiz). The depressed plateau has all the appearances of the modern coastal plain of the continent, as if formed in the same way, which would indicate a long continued elevation of the region as great as is the present submergence. This shelf is traversed by great valleys and fjords, and its margin is indented by corresponding embayments.

The western side of the Florida mass shows the continental shelf submerged to a depth of about 300 feet, or somewhat more, beyond which there is a steep descent to 10,000 feet. The northern slope of the Mexican basin is not so precipitous as that of the Florida shelf (section *A A′* on map). Moreover, in the vicinity of the Mississippi fjord there is a terrace like the Blake plateau submerged to about 4,000 feet. North of the Yucatan banks there is a precipitous descent (section *A A′* on map) from the shelf (which is there submerged from 50 to 300 feet) to the floor of the Gulf basin, about 12,000 feet below the surface. This trough continues to the isthmus of Tehuantepec.

The continental shelves also occur in the Caribbean sea and the sea of Honduras. These basins are separated by the Honduras and Rosalind banks and Jamaica. On the northern side the sea of Honduras is sepa-

rated from the gulf of Mexico by the Yucatan banks and Cuba. Owing to the demarkation just given and the great depths of the central basin, the necessity for a distinctive name in future discussion has caused me to give the basin the appellation of the sea of Honduras. The imperfect demarkation of the submerged shelves or terraces in the two seas named may partly arise from fragmentary knowledge, due to scanty soundings in some portions of the basins. The deeply submerged Cayman ridge, terminated by the Misteriosa banks, the insular plateau in the eastern part of the Caribbean sea, and the extended plateaus off the Honduras banks, about which we know very little beyond their general submergence to depths of 4,000 or 5,000 feet, suggest old coastal plains, now beneath those seas, and consequent pauses in the terrestrial oscillations at those stages.

It should be noted that the gulf of Mexico and Caribbean sea are generally broad valleys (sections *A A′* and *C C′* of map) and have their counterparts on the Pacific side of the continent; but the sea of Honduras is different, being composed of two very deep channels, almost land-locked on both sides, but situated between the mountain ridges of Jamaica, Haiti and Cuba, rising from 7,000 to 9,000 feet above the sea. The sea of Honduras reaches a depth of 20,000 feet, while the Caribbean basin descends to 15,000, and the gulf of Mexico to only about 12,000 feet.

### *DROWNED VALLEYS OR FJORDS.*

The submerged valleys may be divided into three classes—the notable embayments in the continental plateaus, the valleys crossing the submerged shelves, generally at right angles to the mountain ranges of the land, and the valleys or fjords parallel to the Antillean chains of mountains.

The embayments are everywhere notable at the terminations of the fjords, and where several such end near together they are broad and conspicuous. As the fjords and embayments coalesce and are more or less apparent through all of the detailed contours, it may be well to describe them at the same time.

Lindenkohl* has deciphered the records of the canyon of the Hudson, now submerged to 2,832 feet, where the plateau is depressed to only 600 feet below the surface of the sea. He has also found in the same plateau another fjord with a depth of 2,334 feet. This is a continuation of the united valleys of Great Egg Harbor and Little Egg Harbor rivers. The Delaware extension is indicated on the map, but not extended for want of the necessary soundings. Along this section of the coast the continental border descends precipitously from about 400 to 8,000 feet.

* American Journal of Science, vol. xli, 1891, p. 490.

From the Susquehanna the special study of the writer begins. Its old channel is now buried and passes under the peninsula of Maryland, where the deposits of sand have extended the surface of the land. The coastal currents have done much to obscure the old channels by depositing sand in them, for the water is deeper than 200 or 300 feet only on approaching the margins of the continental shelves, and there, as well as on the lower slopes of the plateaus, the drowned valleys reappear. Thus the Susquehanna fjord is 6,420 feet where the plateau rises 1,800 feet above the channel. Again, where the depth reaches 9,846 feet, the rocky boundary of the canyon is still 1,500 feet above its drowned floor. Even at 12,000 feet the fjord opens into an embayment in the edge of the plateau, and has a width of 40 or 50 miles, or about that of the lower Mississippi flood-plain.

The fjords of Blake plateau are especially remarkable. In spite of the tendency of the Gulf Stream to silt up the transverse channels and the filling produced by the coastwise drifting sands, and in spite of the sometimes incomplete soundings, several important drowned valleys have been discovered. The Santee and Pee Dee rivers formerly joined and cut a deep channel across Blake plateau, the soundings indicating channels still open to the depth of several hundred feet. The old Savannah valley has cut its way through the whole remnant of Miocene formation, as shown by well-borings submitted to Mr Louis Woolman, who has found in the higher limestones the characteristic microscopic Upper Eocene shells, and is now buried to a depth of 250 feet by more recent sandy deposits. We do not know that this is the greatest depth, since the wells may not be in the center of the buried valley, which is several miles wide. Crossing Blake plateau, a submerged valley in line with the Savannah embayment is still left open to a depth of over 1,650 feet, with the plateau depressed to 1,950 feet more below the surface of the sea. After traversing Blake plateau for a distance of 250 miles, this fjord enters the deep embayment in the edge of the continental shelf.

Another remarkable submarine valley is that in line with Altamaha river.* At a point where the plateau is submerged 2,500 feet this canyon-like depression reaches a depth of more than 7,800 feet beneath the sea-level, and 300 miles farther off shore the depth is 13,560 feet, with the outer embayment considerably deeper. This valley is comparable to the canyon of the Colorado river of the west. The depression which the writer has called the Bahaman fjord also crosses the same plateau just north of the group of small insular remains of the coastal plain which

* Eastward of this region the soundings are not numerous, but at the edge of the plateau evidence appears to show that the canyon is much deeper. Although this depression at 7,800 feet is not confirmed by a chain of soundings, its absence would not affect any other portion of the argument, as it was an after observation.

now constitutes the Bahama islands and banks. The configuration here indicates that formerly the Bahaman valley drained the northern side of what is now the ridge underneath the Gulf Stream where it emerges from the straits of Florida. This channel is entirely submerged to depths of from 2,064 * to 10,314 feet in a distance of 350 miles. Near its mouth the fjord is bounded on one side by the plateau, rising 6,800 feet above its floor, and on the other by the watershed between it and the Altamahan fjord, which has also the great elevation of over 5,000 feet, although so deeply submerged. The Abacan fjord (named from the adjacent island) differs from the last three in that it passes between low islands, though crossing the same subcoastal plateau. It extends eastward from a point west of the Bahamas, where the depth is nearly 2,400 feet, with the transverse ridges of the straits of Florida considerably higher. Thirty miles eastward it is 5,688 feet below sealevel, and increases to a depth of over 10,000 feet south of Great Abaco island, where it joins another canyon-like depression no less clearly indicated by the soundings. The Abacan fjord is of particular interest as showing that the Gulf Stream has taken possession of three different valleys. Its presence also indicates that while the Gulf Stream has probably deepened the divide between the northern and southern valley (deepest sounding, 2,064 feet), yet the valleys existed before the Gulf current, for, while eroding the higher cols, the current tends to fill up the deeper channels, into the quieter waters of which the sediments settle; but the Abacan channel, not receiving the Gulf Stream, except where crossed at its head, has not been filled by the débris of the current-scour even in its upper reaches, thus suggesting that this marine current has not made, though it may have modified, the valley of the Floridian strait.

The Androsan fjord is 4,500 feet deep at the head of the tongue of the ocean and 8,940 feet near the mouth of the Abacan, below which the two valleys are united and enter the oceanic embayment with a depth of 14,178 feet. Here the soundings indicate an interesting feature. Into this embayment, which is 120 miles wide, there enter four great fjords (Altamahan, Bahaman, Abacan and Androsan). The embayment is bounded on the northern side by an island, now submerged to a depth of about 4,000 feet, and in front of it there is another, rising to 5,000 feet above the floor of this arm of the Atlantic basin.

All of the submerged channels crossing the Blake plateau have directions at right angles to the mountain ranges of the continent, and apparently represent continuations of the existing rivers. There are also many short, drowned canyons among the Bahamas and banks, but the soundings are

* In latitude 27¾°, longitude 79¼° W., the channel has reached a depth of 3,882 feet, as shown in an unpublished sounding of the Hydrographic Office.

not everywhere sufficiently numerous to work out the details. Among the Bahamas the Exuman depression increases to a depth of over 6,000 feet, and may belong to the same group of drowned valleys as those already described, or possibly to those parallel to the mountain folds of the Great Antilles; still it is 250 miles distant from any mountains.

In the gulf of Mexico the similar submerged valleys exist, and their interpretation has been confirmed by recent studies of the writer, in which evidence has been found of several old valleys, now somewhat filled in their lower reaches. This has led to investigation of the character of the depressions, which in turn has bound together in indissolvable union the existing land valleys and the submerged fjords. Thus the drainage of southern Florida flowed by Key West, and the channel is recognizable near that key at a depth of 2,400 feet, where the adjacent submerged land is only 840 feet below tide. With rocky banks of 600 feet in height, it is still apparent at a depth of 5,600 feet, and just beyond it joins the great Floridian fjord. On the western side of the Floridian mass the Tampan, Suwaneean, Apalachicolan and other fjords all incise the rapidly descending continental margin to a depth of over 10,000 feet.

The Apalachicolan, Escambian, Mobilan and Mississippian fjords all unite to form the great Mississippi embayment of 9,000 feet in depth, and where deeper the basin becomes a channel-like depression, increasing to 12,000 feet, or about the full depth of the Mexican gulf. The Apalachicola represents a broad valley extending far up into the Appalachian mountains, and so do the Escambia and Mobile rivers—all the valleys being several miles wide. Even in its upper portion the Mobilan fjord has a depth of 700 feet, and the shelf which it crosses is itself submerged to 1,500 feet. The Escambian fjord shows a depth of 1,800 feet beneath its walls, which are 1,200 feet below tide level. All these drowned valleys are recognizable in the soundings to a depth of over 10,000 feet. West of the Mississippi there are other fjords which are apparently not connected with the greater drainage of the modern rivers. One of these indicates that during one of the periods of elevation the Mississippi made another channel west of the present one. The Red River canyon was also independent before it united with the Mississippi on its present flood-plain, which is from 30 to 80 miles wide. Again, the rivers entering the northwestern region of the gulf have continued seaward, to form fjords and other embayments. Thus in front of the Rio Grande drowned valleys are recognizable, descending from about 600 feet to 8,280 feet, where the sides of the valley rise 3,000 feet above the bottom of the depression. Although the soundings are sometimes scattered, there are enough to indicate these depressions with clearness, and the occurrence

of the great depressions in lines with the existing embayments seems fully to warrant the inference of formerly continuous drainage systems.

On the northern side of Yucatan the descent from a depth of 300 feet to 12,000 feet is generally precipitous (section *A A′* on map); but crossing the submerged terraces one great valley is known—the Yucatan, which is apparent from 3,500 feet below the surface to nearly 12,000 feet, with a short but deep tributary from the west. Its landward connections have not yet been recognized.

The Floridian valley is drowned for a length of about 400 miles, and descends from a depression of 2,064 below the surface to 6,000 feet opposite Havana, and to a depth of 12,000 feet after passing the line of the Florida and Cuba shelves. Several confluents tributary-like have already been revealed by the soundings, as those from Havana, Matanzas, Cabanos (3,075 feet, with the adjacent shelf only 1,200 feet) and two large branches from between the Bahamas and Cuba, with cols not over 1,500 feet below the surface. Longitudinal and transverse sections of the Floridian fjord are shown on the accompanying map. The slow deepening and increase in size of this Floridian valley is much like that of a river. Part of this valley joins the Abacan fjord.

The fjords of the sea of Honduras are remarkable. Of the type thus far treated, that of the gulf of Cazones is most notable. Near the head of the gulf the submarine valley is 2,250 feet deep, and it has tributaries from Cochinos and Xagua bays. Still enclosed between the land and the keys for a distance of 70 miles, the fjord of Cazones increases in depth to 7,500 feet before joining the outer valley. The Cayman represents another depressed channel uniting with that from the gulf of Cazones.

Fjords parallel to the mountain folds are best represented by the narrow channel north of Haiti (the Haitian, shown in section *C C′* on the map). Its source north of Cuba is depressed 1,500 feet below tide, but it deepens, so that at its mouth it is 13,746 feet below the same level. While this drowned valley cuts through the continental shelf, it is parallel to the mountain ranges and part of this depth may have been due to folding by mountain movements, such, however, as did not close the submerged valley and form a basin. There are other notable valleys extending westward from Haiti which are also parallel with the mountain folds. These connect with Bartlett deep south of Cuba. This last depression forms a narrow trough extending westward for 600 miles and strikingly resembles a land valley; but it reaches to the enormous depth of over 20,000 feet, while its western end is closed by Honduras and Central America. It lies between the great mountain folds of Cuba, Haiti and Jamaica, but these mountain disturbances grow weak before reach-

ing the western end of the deep. Interpreting it as originally a level valley, Bartlett deep may not indicate a general elevation of the adjacent lands to the amount of the subsidence, which here was probably amplified in the foldings of this mountain region. Of the same character is the depression between the Virgin islands and the nearest of the Windward ridge (Santa Cruz), where the depth is 15,000 feet, although the outlet to the basin is not known to exceed 10,000 feet. It seems probable that both these depressions are submerged valleys, and that the epeirogenic movements of the region have not been obliterated by the orogenic, since all of these remarkable deeps have great tributary fjords, of the ordinary type, which are known to descend to considerable depths.

The Caribbean sea is essentially a basin, but it receives numerous short tributary canyons. That from the gulf of Paria (a mouth of the Orinoco) is very noticeable, extending as it does to a depth of 12,000 feet. Between South America and Granada the Windward ridge is depressed to 2,526 feet. North of the Grenadines the sea is less than 1,600 feet, with a westward bound channel recognizable in the present soundings to 3,600. Between Saint Vincent and Saint Lucia the sea is reduced to a depth of less than 3,000 feet, with apparent fjords increasing to over 6,000 feet towards the west. North of Saint Lucia the submergence has depressed the ridge to 3,500 feet, but with drowned valleys noted to 6,000 feet, westward bound. North of Martinique the ridge is 4,000 feet below the surface, with westward opening valleys shown to a depth of 6,000 feet. North of Dominica the depth is 3,300 feet, with a westward drainage. Beyond Guadeloupe the ridge is submerged to 2,400 feet, with drainage in both directions. Beyond these small islands there is the great deep of the Virgin group noted before. It is apparent in the hydrography, from South America, that the Windward ridge extends and forms a separating barrier between the Atlantic and Caribbean sea, nowhere lower than between 1,600 and 4,000 feet below tide-level, with the valleys generally declining westward. The eastern side of the ridge descends rapidly to the Atlantic, with relatively short valleys strongly suggesting subaërial sculpture.

The recent submergence is further marked by the depth of the Orinoco, which reaches to 360 feet below tide level at points 400 feet from its mouth.

South of Haiti and of Jamaica the fjords are apparent in the bays. Thus Morant bay, the Saint Lucia and the Mosquito cove deepen rapidly to 600 feet or more, while the depressed coast is not flooded to a greater depth than 60 feet. The valley of Savannah la Mar is nearly 2,000 feet deep, yet the coastal shelf is not more than 600 feet below the surface; nor do we need to go to land-locked bays for drowned chan-

nels. On the Honduras banks, where the water is about 175 feet deep, there are several drowned canyons as shown in figure 6. On the northern side of this submerged plain the channel forms a canyon traceable to 690 feet and on the southern side to 940 feet. The passage between Rosalind and Pedro banks, with a depth of 4,400 feet and a width of 80 miles, connecting the Honduras and Caribbean seas, is only the union of the valleys on the opposite sides of the ridge, apparently broadened and deepened by marine currents established when the submergence was half or less that of the present. The channel between Pedro bank and Jamaica, with a depth of about 3,000 feet and width of 40 miles is of similar character. That between the sea of Honduras and the gulf of Mexico reaches a depth of 7,000 feet and a width between the banks of 100 miles, or 140 miles from land to land. This is of like

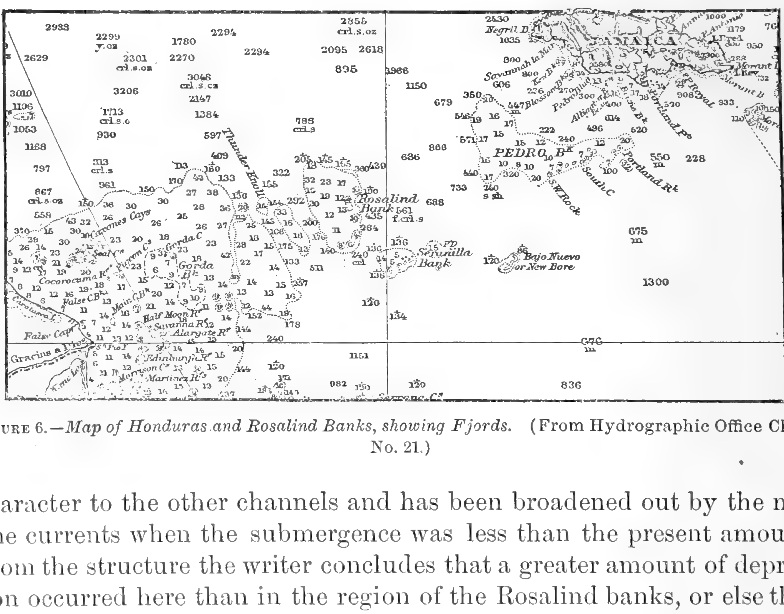


FIGURE 6.—*Map of Honduras and Rosalind Banks, showing Fjords.* (From Hydrographic Office Chart No. 21.)

character to the other channels and has been broadened out by the marine currents when the submergence was less than the present amount. From the structure the writer concludes that a greater amount of depression occurred here than in the region of the Rosalind banks, or else that the submergence was earlier. The physical character of both these passages is modern, in the region of least orogenic disturbances, and their depths, inferior to those of the fjords (the Yucatan being in juxtaposition to them), show that the outlets of the present basins were not across these ridges. One other fjord must close the list. This has a depth of 7,000 feet within the limits of the lower terrace off the Honduras coast. It is probably a continuation of Segovia river.

On the Pacific coast the somewhat scanty soundings prevent exhaustive study, but it seems that the shelf depressed off the coast of Centra

America to 600 feet or less is much narrower than on the Atlantic side of the Antilles, or is wanting (the basin of Panama gulf, which is like a submerged terrace, is an exception); but deep water often approaches near the land, and in places fjords may be seen. A quite noticeable feature occurs south of the isthmus of Tehuantepec and a similar one south of the gulf of Panama, where broad, deep basins of the Pacific ocean extend landward as if they were once continuations of the Mexican gulf and Caribbean sea.

This array of data in the geomorphy of the vast and only partly surveyed Antillean region, although scanty in proportion to the area, suggests physical problems which should no longer be overlooked. Interpretations may differ, but the facts are of undoubted significance and seem to the author strongly to indicate vertical oscillations of great amplitude during the course of development of this and neighboring districts.

### Characteristics of the lower Reaches of the Land Valleys.

As the correlation of the valleys and the submerged canyons will follow, the general characteristics of the depressions of the country traversed by the lower reaches of the rivers may be noted, especially as the descriptions of their forms are not readily available. After leaving the older formations and entering the less coherent Cretaceous and Tertiary strata, the rivers pass over the gently sloping coastal plains, which may have a width of 200 miles or more and a descent of 400 or 600 feet before reaching the existing coast. But where the plains are not over 250 feet above tide, the rivers occupy broad troughs. Even at 200 miles from the sea the valleys may be from two to four miles wide, and where only partly filled by the deposits of later date the flats are characterized by flood-plains and swampy areas. Farther down their courses the valleys widen and are delimited by bluffs rising perhaps 50 or 100 feet above the streams which touch them at only occasional points. The drainage of the swampy reaches is often retarded by the necessity of the streams crossing durable rocks which have become exposed, owing to the gentle deformation of the surface, during terrestrial undulations, or by a change in the course of the stream. Nearer the sea the form of the valley becomes obscure, owing to the filling with sand or alluvium during the more recent epochs and to modern sedimentation. Here the shallow valleys are apt to be swampy, but limited by hills rising from 25 to 75 feet, more or less modified, owing to interruptions on account of the entrances of great lateral branches. As all the features are low, but on a broad scale, with the depressions from five to ten miles wide, on reaching the coast the true characteristics of the valleys are best appreciated

in leveled sections. Near the coast the broad valleys are commonly deeply buried, even to hundreds of feet. In the case of the Mississippi, at New Orleans, a well to a depth of 900 feet below the surface did not reach the floor of the old valley of erosion. To give a list of examples would include all of the valleys of existing rivers and others now completely buried. These buried valleys are discovered by well borings, and in other cases inferred by the forms of the valleys themselves, whose outlines are not completely obliterated.

### Analogy between the submerged Valleys or Fjords and the land Valleys and Canyons, with Inferences as to former continental Development.

When the valleys of the southern Appalachian mountains, whether two, four, twenty or forty miles wide, are compared with the submerged Antillean depressions the resemblance is complete. Even the embayments into the continental plateaus, characteristic of the expanded mouths of the fjords, are no greater than the present embouchures of many rivers or their flood-plains. The only difficulty in accepting these drowned valleys as those of the former land depressions is the great depth to which they reach. Where the soundings are numerous, as they are in some localities, the submarine contours show the drowned valleys continuously from where the surface coastal currents cease to act to the greatest depths. Again, these flooded valleys terminate in broad embayments, which are greatest where several fjords leave the plateau together, just as the divides between the neighboring rivers are gradually reduced beneath the general level of the plateau, owing to the double denudation on both sides of the ridges.

The submerged valleys have their tributaries coming from different directions, as is the case with rivers. In some places the fjords have steep walls, while again they are V-shaped or broader valleys, a few miles wide. The direction in relation to the mountains is at every angle, but the prevailing systems are at right angles to the mountain ranges of the land, and accordingly the depressions are not mountain folds. Two or three fjords are parallel to the mountain folds, and may have been deepened by the movements of an orogenic nature. The valleys commonly cross coastal plains of undisturbed strata, which largely belong to the later geologic formations. All of the drowned valleys are connections or continuations of the rivers of the continents or islands. The fjords are recognizable for distances from 50 to 250 miles, and in one case for 600 miles.*

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* See foot-note, p. 140.

From all of these considerations the writer has been led to conclude that the fjords are land valleys greatly depressed. Once in the progress of our science it was supposed that fissures were formed by plutonic forces and left open. This vision of great open fissures belongs to the past. The drowned valleys diverge in all directions, and the valleys generally are not from orographic folds, except perhaps two or three in part; nor have the epeirogenic movements defaced their character so as to obscure their resemblance to land forms. What inductions are we to make? Can we deny that these systems are old rivers because they are depressed two miles or more? Must we not accept the physical evidence of the great submergence of the land as here recorded, just as we accept the evidence of the great changes of level registered in the older geologic formations?

The gulf of Mexico appears to have been a plain, with the fjords and embayments reaching nearly to its greatest depths. On a smaller scale, it resembles the Mississippi valley, or the country between the Appalachians and the Rocky mountains. Such being the case, its floor was elevated somewhat more than 12,000 feet, and over it drained the Antillean rivers, except the short streams entering the Atlantic basin. It was this precipitous drainage that has removed most of the coastal plains in front of the Windward islands.

Caribbean sea was also another basin which apparently was once a plain, as indicated by the deep fjords, although the explorations are less complete than those of the Mexican gulf. The Windward ridge has been sufficiently investigated to show that the drainage was mostly to the west; but between the Virgin islands and Santa Cruz the natural land valleys appear to have been partially deformed by orogenic movements.

The sea of Honduras is unlike the other two Antillean depressions, as it is not basin-like, but composed of two valleys, now of great depth. These are parallel to the mountain folds. While the land valleys run into these channels, as in the other cases, yet their greater depth, reaching to 20,000 feet, impresses one as being so excessive, and their occurrence between the mountain ranges of from 7,000 to 9,000 feet, elevated in recent times, is so suggestive of orogenic action that I am inclined to attribute part of the subsidence to an abnormal depression of an orogenic fold, though of such a character as not to obliterate the form of the valley. This hypothesis would remove the necessity of supposing that the Great Antilles stood 20,000 feet higher than at present. Such unequal depression is in accord with continental movements already described, but only part of the enormous sinking of the floor of the sea of Honduras could be assigned to orogenic movement, as is shown by the deep lateral fjords.

Through the physical study, the writer infers that the Antillean continent lately existed somewhat as shown by the drainage, but in the various oscillations of level Central America was warped upwards and cut off the western drainage, which appears to have extended into the Pacific ocean, as shown by the basins opposite to the gulf of Mexico and Caribbean sea on the southern side of the isthmuses of Tehuantepec and Panama. While the barrier of Central America was being raised, as illustrated by measured examples already cited on page 108, the Antillean basins sank. On the surface of the land a good example of similar movement may be seen in the Jordan-Akabah valley, which has sunk bodily for thousands of feet to 2,000 feet below sealevel, yet without obliterating the topography of the Jordan valley, even where obstructed by the transverse barrier between it and the gulf of Akabah. As to the dates of the deformation of the Antillean continent we shall inquire later.

Accepting the foregoing inferences as to the meaning of the submerged valleys and plains, it would appear that the magnitude of the continental elevation varied; that after making allowances for foldings and amplified marginal depressions the northern side of the Mexican gulf has suffered a depression of not less than 8,000 feet and perhaps somewhat more; that Yucatan has gone down 12,000 feet; that the Greater Antilles have been depressed 10,000 or 12,000 feet and the southeastern margin of the continent nearly the same amount. While the Caribbean basin has in part become depressed to about 15,000 feet, yet it is hardly likely that any part of the surrounding lands except mountain ridges ever stood at that elevation above their present surfaces. The two Americas were united and the Atlantic currents were deflected eastward. While the Antillean lands of that day were greatly elevated, the plains of the now depressed basins were at no great elevations above the Atlantic, between which and the Pacific some elevated insular masses were apparently being slowly pushed up. While the Antillean elevation lasted long enough for canyons to be cut back to the depths given, yet the time was too short to allow of the dissection of the interior of Florida and the border islands by deep canyons. The climate of the elevated continent with the attendant meteoric conditions must have been quite different from those prevailing today.

## Mid-Tertiary Subsidence of the Region of the West Indies.

The earlier terrestrial condition of the Antilles will be passed over after stating that in the Cretaceous period, or before extensive accumulations of mechanical deposits were formed, the sediments were mostly

derived from localities now depressed beneath the sea or buried by later accumulations; so also from the Cretaceous days, or before, to modern times great volcanic activity in one locality or another has been added to the geologic forces of the region of the West Indies.

During the earlier part of the Eocene period a portion of the West Indies was elevated, but this elevation does not seem to have extended to the adjacent continental area. During the later Eocene and most of the Miocene period only a few islands appear to have existed in the seas of the West Indies and Central America, and the accumulations of strata reached extensive proportions. As the Miocene often succeed the Eocene strata without a break, they form a physical unit. In Cuba their united thickness, actually observed, is 1,400 feet, with a faulted structure, which indicates a total development amounting to 2,000 feet. Along Chattahoochee river the Eocene is 1,400 feet thick. At Jacksonville, Florida, the upper Eocene, beneath 400 feet of overlying accumulations, extends to a depth of 1,500 feet without reaching the bottom beds. At Galveston 2,000 feet of upper Miocene (Dall) alone have been revealed in a well. At Savannah Miocene strata have been denuded to a depth of 250 feet below tide in the buried valley, and in southern Florida, beneath the late Pliocene basin, only four feet of upper Miocene strata remain (Dall). In Jamaica the Eocene and Miocene strata aggregate 5,000 feet (Sawkins), and there the deposits have been raised to 3,000 feet above the sea.* The Miocene formation of San Domingo is 2,000 feet thick and raised to an altitude of 3,855 feet (Gabb). The greatest elevation of the Miocene in Cuba appears to be 2,300 feet south of the Sierra Maestra.† Similar limestones form the divide of the isthmus of Tehuantepec, and on adjacent hills rise to 1,000 feet,‡ with the maximum height unknown. At Panama the Miocene strata occur to a height of 500 feet on some hills rising out of the harbor (Maack),§ and in the neighboring parts of Costa Rica they rise to 3,000 feet (Gabb). Similar strata also form the divides between the valley of Atrato and the Pacific ocean, with elevations of 763 feet and higher, but the maximum elevation is not given. Thus in the Miocene times, so far as can at present be determined, only a few small islands of Cretaceous, with some plutonic, rocks could have risen above the common surface of the Atlantic and Pacific oceans, and all of the topographic and hydrographic features are post-Miocene.

In the Miocene period there appears to have been a great subsidence of many portions of the Antillean and continental regions. Along the coast

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* See reports on Jamaica and San Domingo, cited before.

† J. P. Kimball, Am. Jour. Sc., Dec., 1884.

‡ Report on "Isthmus of Tehuantepec," by J. G. Barnard and J. J. Williams, Appleton's, 1852 (see geological section).

§ "Isthmus of Darien Ship Canal," U. S. Navy Department, 1874.

of the continent diatomaceous and foraminiferal earths occur in the middle Miocene beds. This is true also in Jamaica, and apparently of Cuba, where radiolarian deposits at the eastern end of the island appear to belong to the same date. In Barbadoes Messrs Jukes-Browne and Harrison * have described great deposits of radiolarian earths. They assign the oceanic deposits provisionally to the Pliocene, but do not object to the earlier age, as they had not the data for settling the question, but they established the succession of insular strata and the wonderful amount of subsidence. The related rocks in the island do not form a series for close comparison of the age of the abysmal earths. They lie on the greatly eroded surfaces of what may be Cretaceous deposits (judging from dynamic conditions) and unconformably underlie limestones of probably the latest Pliocene epoch, if correctly correlated with the rocks of the Greater Antilles. Under these conditions it may not be straining the evidence to place the Barbadian earths in the Miocene system, under which the geomorphic changes of the whole region would be in harmony. Accordingly, in the Miocene period there appears to have been a great subsidence, extending from the West Indies to New Jersey (apparently commencing a little earlier in Barbadoes and later in the north), the beginning of the stupendous oscillations that culminated in the continental Antilles and ended with the modern depression of the region of the West Indies.

## The Antillean Continental Extension in the Pliocene Period.

Throughout most of the Pliocene period there was an extensive elevation and development of the Antillean region. In part, this elevation may have commenced in the later Miocene; for, according to the paleontologic studies of Mr Robert Etheridge † on the fossils of Antigua (Eocene, according to Jukes-Browne), Anguilla and part of Trinidad, the upper Miocene rocks are absent, either from not having been deposited or from subsequent denudation. Littoral Miocene beds are also wanting in Barbadoes and probably in other regions. In Cuba, San Domingo, Jamaica and other places, as in Florida, the upper Miocene beds are found. In places the earliest Pliocene beds appear to be also found as a stratigraphic unit with the Miocene in Florida (Dall); ‡ consequently the great continental elevation in some regions seems to have commenced at the end of the Miocene and in other places in the early Pliocene period; but the Tertiary seas were being gradually restricted, from the earlier Eocene times, along the continental margin.

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* The Geology of Barbadoes, by A. J. Jukes-Browne and J. B. Harrison, Quar. Jour. Geol. Soc. London, vol. xlvii, 1891, pp. 197–250, and vol. xviii. 1892, pp. 170–226.

† See the reports on San Domingo and Jamaica.

‡ Bull. U. S. Geol. Surv., no. 84, cited before.

Turning to the land features, it appears that the more or less upturned Miocene beds were being extensively eroded into broad valleys, with the fjords creeping inland. Even the little valley of the Yumuri of Cuba was excavated to a width of three miles, and the same is true of several valleys in Jamaica, San Domingo and Costa Rica, which are excavated out of Miocene limestones and other strata. The valley of Atrato, in Colombia, which is 40 or 50 miles wide, is more recent than the Miocene period. The elevated valleys, with bases 1,500 feet above the sea, in the Trinidad mountains of Cuba, and similar valleys in Jamaica, up to 3,000 feet, have been elevated much more recently than even the Pliocene erosion which molded their forms to a great extent. Such valleys are being now produced by widening of the rapidly growing canyons. In short, at that time the Antillean mountains were not relatively so high above sealevel as now. The Pliocene drainage reduced the valleys to the lowest level, and these were miles in width. It was then that the modern topography was first well established. The duration of the epoch of erosion was long, and the formations which were degraded were those that formed the surface of the country which was largely covered by Miocene deposits. Thus the Matanzas fjord was first entirely excavated to a depth of 1,500 feet before joining the outer fjord. The Pliocene deposits of southern Florida occupy a broad, shallow basin, with the older Miocene formations rising on both sides.* In short, throughout most of the Pliocene period the continental elevation continued with the degradation of the surface into canyons extending far inland, but not so far as to carve deep valleys into the interior of the then elevated tablelands which now constitute the coastal plains, except such as are now buried to the depth of a few hundred feet.

The geologic development of Central America is yet somewhat hypothetical. That the drainage was toward the Pacific is highly probable, if not certain, since the characteristics of the adjacent portions of the ocean bed indicate a continuation of the Gulf and Caribbean valleys and plains; but in the great oscillations of the land from abyssmal depths to continental elevations of 8,000 or 12,000 feet some insular masses doubtless rose into prominence. Such heights would refer mostly to the region of the Greater Antilles and the adjacent continents, for the Gulf and Caribbean plains must have been low. The former tablelands are in part illustrated by the modern great plateau basin of Mexico and the tablelands of Guatamala, which rise from 6,500 to 8,000 feet above the sea, or by the still higher tablelands of Asia.

During the Pliocene elevation there was at least one volcano in Jamaica,† and some of the volcanoes of Central America appear to have

* Bull. U. S. Geol. Surv., no. 84, "Neocene Correlation Paper," by W. H. Dall, map, page 156.
† Geology of Jamaica, p. 120.

then been active (Gabb), as well as several volcanic cones in the Windward group.

The surveys of the sea of Honduras are much less complete than those of the gulf of Mexico, but they are sufficient to indicate that a great portion of that sea was shrunken to narrow limits, if not entirely drained. Still, of this we have no proof at present, as the regular continuity of the tributary fjords to the greatest depths is not shown by the incomplete soundings so far made. In the oscillations of recent geologic times the deeper portion of the Honduras basin may have remained a sea and formed a retreat for such antique types of life as may be found in the deeper Antillean waters.

## Drowning of the Pliocene Lands and Burial beneath marine Accumulations.

In Cuba, Jamaica and San Domingo, resting upon the upturned edges and denuded surfaces of Miocene and earlier formations, there is a deposit of soft, earthy, white or creamy limestone, made out of the mechanical residue of older limestones, with some small masses of corals and shells. All the observed species in Cuba * are the same as the living ones.† To this formation the writer has given the name of the Matanzas series. Owing to the modern facies of the organic remains, Salterain ‡ has included it in the post-Pliocene, but states that it may be Pliocene. The accumulation occurs somewhat bedded, and has a thickness of about 150 feet. The beds generally lie at low angles, dipping (2° to 8°) toward the coast or are nearly horizontal. This chalky limestone is soft and can easily be cut, but soon hardens on exposure. It can be used for building purposes or as road metal. The lower bed, in which there are some limestone pebbles from the older formations, has been seen to rise to nearly 400 feet in altitude. It sometimes forms the barriers in front of the modern bays, and these are then apt to be incised by recently formed canyons, of which the outlet of the harbor of Cienfuegos is an example.

In geomorphic position the Matanzas formation corresponds with the Lafayette of Mr W J McGee, and also with some marine deposits of southern Florida. Professor A. Heilprin has also found the same formation on the northern plains of Yucatan. § From all the evidence before the writer, he has placed the deposition of the formation at the close of the Pliocene period, though in fact it may extend somewhat later. During the

* "Geographical Evolution of Cuba," by the writer, in preparation.

† Dr W. H. Dall and Mr Charles T. Simpson kindly determined the fossils for me.

‡ "Apuntes para una Descripcion Fisico-Geologica de las Jurisdicciones de Habana," Madrid, 1880, p. 20.

§ "Geological Researches in Yucatan," by A. Heilprin, Proc. Acad. Nat. Sci. Phila. for 1891, pp. 136–158.

Matanzas depression, Cuba and the West Indies were reduced to small islands without surface enough to furnish the red residual loams and quartz gravel, such as make up the Lafayette of the northern continent.

The Matanzas formation is widespread throughout the Antilles. In San Domingo Gabb * describes this low lying formation as post-Pliocene, on account of the modern aspect of the fossils, and calls it the "coast formation," a name somewhat confusing, as it is also given to the modern coral reef formations. Its thickness is about 200 feet.

In Jamaica Sawkins * and other geologists describe the "white limestone" as Miocene, but by some circumstance have tabulated the formation as post-Pliocene. It is a very much disturbed formation 2,000 feet thick and elevated to 3,000 feet above tide, altogether unlike the later deposit in the Antilles. This has led to errors in correlations. In his summary Sawkins describes the surface of the "white limestones" as a "white marl" derived from the limestones; but in the excellent detailed local descriptions in numerous places he shows that the "white marls" rest unconformably upon the "white limestones" or older surfaces, the marls having a thickness of not more than 200 feet. In Cuba, where unconformity or other criteria are not apparent, it is somewhat difficult to distinguish the Matanzas limestone from the older Tertiary rocks from which it is largely derived. From the descriptions and also the map of Mr Sawkins, it is apparent that the older Miocene surfaces were enormously eroded before the deposition of the marls, as the latter lie in valleys hundreds of feet deep and three or five miles wide. The fossils found are not abundant, but mostly belong to living species.

A similar so-called post-Pliocene formation with modern fossils has been noted on the isthmus of Panama and on the Atlantic side of Costa Rica respectively by Dr G. A. Maack and Dr W. M. Gabb † lying unconformably on Miocene strata. It occurs up to an elevation of at least 150 feet above the sea and constitutes the eroded hills of the low coastal plain. Dr J. Crawford ‡ notes the occurrence of recent oyster-bearing beds in Nicaragua. He informs me that they reach an elevation of about 500 feet and unconformably succeed Miocene strata. In position the Matanzas limestones are represented on the Atlantic side of the isthmus of Tehuantepec by Mr J. J. Williams in his geologic section. §

Most important are the observations of Professor A. Heilprin. where he shows the occurrence of this soft limestone with some extinct fossils over the extensive low plains of northern Yucatan. There, too, the surfaces are eroded, and the geomorphy is the same as that of the Antilles.

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* Cited before.

† "Isthmus of Darien Ship Canal," cited before, and Gabb's Costa Rica, cited before.

‡ Report of the British Association for 1890, p. 812.

§ "Isthmus of Tehuantepec," cited before.

In Barbadoes there is an extensive capping of "raised reefs or coral rocks," rising in terraces to 1,100 feet, with a thickness of from 150 to 260 feet, as given by Messrs Jukes-Browne and Harrison.* The contained fossils are modern, except perhaps some of the corals. Although the formation is elevated somewhat higher than the same deposits farther westward, yet the geomorphic position, the fossils, and the magnitude and character of the deposits would lead me to correlate it with the Matanzas formation or the latest Pliocene; still the epeirogenic movement possibly began a little earlier on one side of the basin than the other. In Guadeloupe, Anagade, and several of the northeastern Windward islands fragments of the Matanzas limestone appear to exist, but they have not been separated from the Miocene strata. The nucleus of the Windward mass is Cretaceous or igneous, succeeded by Eocene and Miocene strata, most of which has been removed by the stupendous denudation of the region during recent geologic times.†

In Trinidad there is no corresponding calcareous formation; but resting on certain deposits referred to the Miocene and unconformable to it there are the Moruga sands, and possibly some of these beds may be the equivalent of the Matanzas limestone.

Turning now to the continent, Dr Dall has mapped a large shallow basin opening southward, containing a few feet of Pliocene beds. In other localities only two or four feet of Miocene deposits have escaped denudation. Geomorphically the upper marls with recent shells occupy the same position as the Matanzas beds. The basin is such as would have been formed during the Pliocene period of erosion, as already described.

If the writer be correct in the interpretation of the Antillean phenomena the equivalent of the Matanzas formation is found in the Lafayette formation of Mr W J McGee, with which the writer is familiar, over a wide extent of country. The materials of the continent are essentially red or yellowish loams, sands and water-worn gravels, which last occur adjacent to the old waterways. On the higher lands the thickness is about 20 feet, but in the valleys the writer has seen it 120 feet thick, and in the Mississippi channel it is a much heavier accumulation. The formation often showed no stratification where the gravel is absent. When present the gravel generally forms the lower part of the deposit. The materials were primarily derived from the residuum of the rock decay, somewhat varied according to the source, whether it was obtained from the surface remains of

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*Cited before.

†See Transactions of the Royal Academy of Sweden, T. ix, no. 12, 1871, where Professor P. T. Cleve gives a summary of the geology of the northeastern islands of the West Indies. From his paper and other information received from unpublished sources, I should expect to find fragments of both the Matanzas and Zapata formations on those islands, although perhaps the materials would not be of the same constitution as elsewhere.

the metamorphic rocks, of Paleozoic limestones or of the impurities of Tertiary limestones. The old land surfaces furnished an abundance of such material to the exclusion of calcareous organisms, for in the formation no marine life has been found. The Lafayette formation was deposited on the eroded surfaces of all such formations as occur along the coast of the continent of geologic date from the Archean time to the later Miocene period. In the West Indies the physical conditions were different from those of the continent, for there were few islands to furnish sediments and so the Lafayette loams were replaced by the Matanzas limestones. That the lands in the Antilles would have supplied such materials if they had been more elevated is proved by later events in the geology of that region. Thus in a visit to the West Indies the writer was not prepared for the identification of accumulations so dissimilar, but on the discovery of the key it was found that such differences should have occurred.

The Antillean region may be too great an area to bring within the scope of the gentle epeirogenic movements, but beyond the limit of the orographic disturbances the deformation of the earth's crust over the vast region from New Jersey to Mexico shows undulations in the coastal plain of hardly a thousand feet (from 100 feet, above tide, near Cape Hatteras, to 800 feet in South Carolina, 250 feet in Arkansas and 1,000 feet on the Rio Grande). Only on approaching the vicinity of the isthmus of Tehuantepec do the undulations become involved in the recent and great mountain movements. The elevations of the Matanzas limestones from the Windward islands to Central America seem to be only affected by gentle undulations until reaching the zone of transverse but recent mountain uplifts. Herein lie some difficult and unsolved problems. Except in the region of the Pacific barriers and one or two other localities the evidences of moderate terrestrial undulations is markedly shown in the character of the submerged valleys. From the various considerations set forth the conclusion is reached that the Matanzas epoch (about equivalent to the Lafayette) represented a general submergence below the present altitude, not only of the costal plain to from 100 to 1,000 feet, but that the Antillean lands at the end of the Pliocene period were depressed so that only a few islands remained at altitudes from 100 to 1,100 feet lower than today. But at that time there was also another variation in the topography, for the mountains had not their axes so highly elevated above their flanks as they now are, as pointed out on page 123, and as demonstrated by the character of the modern erosion of the recently elevated bases of the mountain valleys.

The epeirogenic movements may not have been quite synchronous; perhaps beginning a little later in the north than farther south and also

ending later in one region than in another, but the general undulations belonged to the same system of changes of level.

## THE EARLIER PLEISTOCENE ANTILLEAN CONTINENT AND ITS DEGRADATION.

After the deposition of the Matanzas limestones and the Lafayette loams, the continent rose to a great elevation, as is recorded in the amount of succeeding erosion. The enormous degradation is one of the physical problems which McGee so strongly emphasizes in his researches in the Lafayette.* He considers it greater than that of the Pliocene elevation. For the Antillean region, the writer is not fully satisfied with his conclusion in this first study, although the filling of many of the old Pliocene valleys was almost entirely removed, and in many places the channels were further enlarged. At present, the writer thinks that the degradation in the pre-Matanzas and in the post-Matanzas epochs was of about the same magnitude, but a longer duration of erosion in the earlier Pliocene period would explain the inferior elevation of that time. In both periods the valleys were excavated so as to leave depressions several miles in width, not merely along the great rivers of the continent, but also along the shorter streams of the West Indies. Thus the Yumuri valley in Cuba was reëxcavated to a width of three miles, and Xagua bay to a greater breadth, for this is only a recently submerged valley. The same is illustrated on the south side of Jamaica (in Vere and Westmoreland parishes) and in Haiti. In Costa Rica the effects of this epoch of erosion are seen in the rounded hills rising out of the low plains and in the broad valleys on the western side of the continent. Everywhere the amount of denudation would indicate slopes corresponding to those of the earlier Pliocene elevation. The fjord of Matansas bay, which has a depth of 1,500 feet within its land boundary, is cut through this latest Pliocene limestone.

While the Pliocene valleys were more or less refilled in the Matanzas epoch, it is certain that they were reopened in the earlier part of the Pleistocene period. It would appear that the present lands of the West Indies and the adjacent parts of the continent stood quite as high, if not higher, than during the Pliocene elevation, so the amount of erosion equaled or exceeded that preceding the Matanzas epoch. At any rate, the fjords are open to the great depths already described.

The character of the drowned valleys, involving the Matanzas limestones and the Lafayette loams, and their physical relations to the succeeding deposits, point to the conclusion that the American continents were united by the Antillean bridge with an altitude as great as that of the

* Cited before.

Pliocene period or greater, or varying from 8,000 to 12,000 feet or more, and, subordinately, that almost all of the drainage flowed into the Pacific ocean. While most of the canyons did incise the frontal margins of the plateaus and receded to great distances in them, yet the elevation did not last long enough for the deep valleys to be completely cut back and leave great depressions in the central portions of what are now the coastal plains. Whether the elevation was great enough to completely drain the sea of Honduras (as the Caribbean sea) cannot be told at present. The great altitude of the Antillean land is no longer a question. The climate of the high lands may have been more or less arid in some localities, like the plateau-valleys of modern Mexico and Guatemala, or even parts of San Domingo.

### Subsidence of the West Indies in the later Pleistocene Period.

The subsidence which followed the earlier Pleistocene elevation is marked by some terraces rising in Cuba to an elevation of 1,000 feet and lower altitudes. This terrace problem needs careful revision before the Pleistocene and later made shorelines can be distinguished over widely separated areas. But both subsidences affected and depressed all of the greater Antilles, Central America, and the coastal margins of the continent from about 25 to 500 or 700 feet lower than now. This depression greatly reduced the size of the larger West Indies and Central America; it also made the coast of the northern continent recede 100 or 150 miles, and drowned most of Florida. The accumulations in Cuba and the other greater Antilles, and also in parts of Central America, consisted of reddish loams and gravels (in the vicinity of the streams), which are now seen at an elevation of 200 feet or more in some regions. To this formation the writer has given the name of the Zapata in his forthcoming paper on the geographical evolution of Cuba.

The Zapata occurs in Jamaica, San Domingo, apparently in Trinidad and widely over Central America.* In Yucatan it appears that the upper post-Pliocene marls of Heilprin belong to this epoch. The sediments were principally derived from the residual loams and gravels left by the solution of the Miocene and other limestones, as there were then sufficient land surfaces to furnish such materials.

Turning now to the continent, the Zapata formation is of about the same age as McGee's older Columbia series, which covers 150,000 square miles of the coastal plain. In Carolina it reaches an altitude of 650 feet, in southern Alabama only 25 feet and along the Rio Grande from 100 to 200 feet above the sea. Physically, it is of the same character as the La-

* The authorities here mentioned have been cited before.

fayette formation, which supplied materials for the newer deposit, which is like the Zapata. The fossiliferous sands and the coquino found in the wells of Saint Augustine, and some marls in southern Florida, are probably of Columbia age, distantly removed from the source of the non-fossiliferous red loams, which were rapidly laid down nearer the sources of mechanical materials.

In the Antilles geologists have not hitherto (Geographical Evolution of Cuba) differentiated the Zapata formation. Gabb includes it with his post-Pliocene "coast limestone" of San Domingo. In Jamaica it is simply called the "alluvium" or the "older alluvium," although in both islands it is from 200 to 300 feet thick. Its position and specialization on the continent were largely the result of the classic labors of Mr. W J McGee, who has surveyed it from New Jersey to Mexico. The geologic forces acting on this widespread formation have progressed quietly over an enormous area of the continent and the Greater Antilles, and in the Lesser Antilles it may, perhaps, be found represented by limestones in places and by clastic deposits in others. The absence of great elevation (probably nowhere exceeding 700 feet or 800 feet) further convinces the writer that the continental oscillations were becoming moderately uniform over a very great area, and this reduces the geology to simplicity; but in the mid-Pleistocene subsidence which lowered the Antillean continent, the ridge of Central America became prominent—an undulation of less than one degree, including orogenic movements, being sufficient.

Whether the Zapata formation extends over the divides in Central America or not is an important question, for that settles the date of the final separation of the Pacific waters from the Antillean seas, but the gravels filling the old valleys in Nicaragua, according to Mr J. Crawford, occur up to altitudes of 500 feet, and it is not improbable that they are of the same age as the Zapata deposits. Under any circumstances, the continent was lost from the date of the Zapata subsidence, which was in the mid-Pleistocene epoch.

## Reëlevation of the Lands at the close of the Pleistocene Period.

From the Zapata subsidence the Antilles rose from 150 to 200 feet above the modern altitude. Then the streams cut out canyons to the depths named, and made many new outlets to the bays, excavated in part out of the Matanzas limestones, but closed by the Zapata loams and gravels. This elevation somewhat enlarged the land area, and increased it to about the proportions shown on the shaded portions of the accompanying map. The Bahamas formed two or three large islands, but neither these nor

the Greater Antilles had any continental connections. The post-Zapata erosion did not exceed from one-fifteenth to one-fiftieth that of the earlier epoch of Pleistocene elevation.

Minor depressions of 100 or 200 feet, or perhaps more in places, followed the post-Zapata elevation, as recorded by the modern terraces, which have not been differentiated from those of earlier date except at one or two places. The elevation of the terraces was not uniform, but accompanied by a slight deformation of the beaches.

The recent movements have been slight and very uniform, as shown by the extensive submerged plains, now constituting banks, by the slight elevation of the modern reefs to a height of 10 or 25 feet, more or less, and the non-deformation of the drowned valleys. In some places the coasts appear to be sinking, as the eastern side of Florida and the Bahamas, while other localities appear to be rising, as the southern side of Cuba.

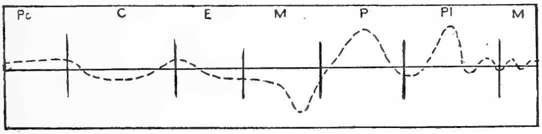


FIGURE 7.—*Oscillations of the Antillean Continent.*

Horizontal line represents sealevel; dotted line, the oscillations; *Pc* = pre-Cretaceous; *C* = Cretaceous; *E* = Eocene; *M* = Miocene (variable in different localities); *P* = Pliocene; *Pl* = Pleistocene; *M* = modern.

The changes of level in the West Indies are graphically represented in figure 7. This hypothetical diagram could not be drawn to accurate scale, either for length of time, represented by the horizontal measurement or for the changes of level, shown in the vertical scale, but in a rude way it illustrates the oscillations of the Greater Antilles in the more recent geologic times.

## THE SEPARATION OF THE ANTILLEAN BASINS FROM THE PACIFIC OCEAN AND THEIR CONNECTION WITH THE ATLANTIC.

It has been shown that the drowned valleys are newer than the Miocene. The partial filling of the Pliocene channels was accomplished at the end of that period, and these accumulations were subsequently removed by the denudation of the earlier Pleistocene period. The fjords trend westward and are traceable to near the floor of the Antillean seas, leaving the inference that those basins were low lands extending to the Pacific side of Central America; but it is to be remembered that this inference is tentative only, and that even if later researches show that the drainage did

not cross the line of Central America the conclusion as to Antillean oscillations will remain. If this inference be true, then the modern islands of the West Indies formed an elevated plateau bridge between the two Americas during the two epochs of elevation, namely, in the Pliocene and in the Pleistocene periods. This conclusion is supported by all the geomorphic structure except perhaps the lower depths of the sea of Honduras, lying between the mountain folds of Cuba, Haiti, and Jamaica. These mountains rise to from 7,000 to 9,000 feet above the modern sea-level; also on the west this basin is bounded by plateaus with ridges and peaks rising to from 6,000 to 14,000 feet above tide, with valleys as low as 2,956 feet (railway survey). The higher peaks are mostly modern or late volcanic, but there are older crystalline rocks, which have been elevated to 12,000 feet since the deposits of Miocene age, which have been forced up by the granite masses to an elevation of 3,000 feet and now form the oldest sedimentary accumulations in Costa Rica.* Dr Gabb concluded that the Miocene formations extended several thousand feet higher than now on the flanks of the granite masses, but have since been degraded. These observations of the deceased geologist are highly suggestive, as his other work has been. It seems to be the key to the orogenic obstructions crossing the Antillean basins, which have been also partly modified by the epeirogenic movements. The latter movements *per se* are not rudely deformatory, but along with them there have been some modern faults and tilting of even the later strata, yet there has not been enough disturbance to obliterate the geomorphic features. A gentle epeirogenic undulation raises the floor of the Caribbean basin, so that its submergence is only 9,000 feet in its western portion. From Gabb's observation, cited, a suggestion appears that in it there is evidence that the Miocene strata have not only been raised 3,000 feet above the sea, but they have been further raised 9,000 feet by the orogenic movement from the floor of the sinking Caribbean basin. Thus there appears a first step in separating the Central American orogenic and epeirogenic movements, the latter being over 6,000 feet.

The epeirogenic deformation of a few feet per mile has a zone across the sloping plateau of from 150 to 250 miles wide on which to expend its forces between the ridges of Central America and the floors of the Gulf of Mexico and the Caribbean sea. How much of the obstruction has been raised in Central America since the time of the Pliocene elevation and how much after that of the Pleistocene period can scarcely be determined at present. However, the difference in the elevation of the Miocene and the upper Pliocene limestones may give a rude measure, and this difference

*See Dr Gabb's papers, "Notes on the Geology of Costa Rica," Am. Jour. Sc., vol. viii, 1874, p. 387, and vol. ix, 1875, p. 198.

throughout the whole region varies from a few hundred to about 3,000 feet. Accordingly the Pliocene deformation may have been about this amount, thus allowing the drainage of the Pliocene continent to reach the Pacific through contracted seas, as before suggested. Moreover, from the geomorphy and the features of denudation in Cuba and Jamaica, it is apparent that a very considerable if not indeed the greatest amount of orogenic uplift has been during the Pleistocene period; but the terrestrial movements which have almost obliterated the Antillean continent have depressed the Antillean area without submerging the Central American bridge.

The deep-sea Echini and other forms of deep-sea invertebrates of the Antillean waters belong to old and Pacific types (Agassiz)*, and geomorphically there was no known deep-sea connection with the Pacific ocean since the Miocene period. Again, the Pacific contours do not support the hypothesis of a post-Miocene extension of the basin of the sea of Honduras to that ocean, as do those of the gulf of Mexico and Caribbean sea, as shown on map. It would appear that the latter basins drained directly into the western ocean in the earlier part of the Pleistocene period.

The Matanzas (or late Pliocene) depression admitted the Atlantic currents with greater depths than at present to the Antillean seas. The Pacific waters probably had access by one or two straits with depths of about 200 feet, according to Crawford's report on the altitude of recent fossils in Nicaragua, for they rise high above the low divide between the waters. The Panama divide is now 287 feet and the Nicaragua is 150 feet above tide, with Matanzas limestones at Panama at an elevation of at least 150 feet. On this question we need more investigation. In the Antilles the terrestrial movements, whether orogenic or epeirogenic, have recently raised the mountain ridges higher than the synchronous elevations of the deposits on the coast. The same, probably true in Central America, also affected by the recent volcanic action, would favor the existence of shallow straits at the close of the Pliocene period between the Antillean waters and the Pacific. With the earlier Pleistocene elevation the drainage of the Antillean continent was again restored to the Pacific ocean between the barriers of Central America, which were now being brought into prominence by combined epeirogenic, orogenic and volcanic movements, thus turning the Caribbean and Gulf plains into basins which became seas at the end of the post-Matanzas elevation; but this Pleistocene continent was not obstructed by barriers to the drainage so as to prevent the general reëxcavation of the valleys which had been partly filled during the Matanzas subsidence.

* Am. Jour. Sci., vol. xxvii, 1884, p. 187.

Pauses in the changes of level must have taken place. Thus the broad Blake plateau, at from 2,500 to 3,500 feet beneath the sea, bears witness to a long period of stability; so at the mouth and west of the Mississippi river another drowned terrace at depths of 4,000 or 5,000 feet repeats the same feature. The channel between Rosalind banks and Jamaica (at 3,000 or 4,000 feet), the Yucatan channel (at 7,000 feet) and the submerged plateau of the Caribbean sea give concordant testimony. The pauses in the elevation would explain certain fjords on the Pacific coast.

But the writer is inclined to regard these broad terrace plains and terrestrial slopes at the baselevel of erosion like the coastal plains of the continent, which required long periods for their completion, as representing the altitude of the Pliocene continent during a considerable portion of the period. In this case the Pliocene elevations were much inferior to the Pleistocene altitudes, but lasted through a longer period of years.

Following the Pleistocene elevation the depression continued so as to permit the deposition of the Zapata loams, but this mid-Pleistocene subsidence admitted the Atlantic waters to the inclosed seas, and probably made narrow straits 300 feet deep between these Antillean basins and the Pacific ocean, subsequently closed by the post-Zapata rise of the land.

Thus it is seen that the Atlantic waters were admitted to the region of the West Indies in the later part of the Pliocene period, to be drained off by the terrestrial elevation in the earlier part of the Pleistocene days with perhaps a shallow connection with the Pacific in the mid-Pleistocene epoch, since which time there has been no connection with the Pacific, but free communication with the Atlantic. This explains the recent admission to the Antillean waters of the deep-sea type of Atlantic fishes to the exclusion of Pacific forms, according to Mr Browne-Goode. Of the littoral fauna of the Antillean waters only a few fishes, crustaceans and mollusks (35 species out of about 1,400 according to Professor Philip P. Carpenter), without the association of any echinoderms or polyps, occur in the waters on both sides of Central America (Agassiz). The Pacific species could have gained admission to the Antillean basin through the straits of shallow depth that united those seas with the Pacific in the latest Pliocene and the mid-Pleistocene depression, since which time there has been no connection.

## Biologic Bearing of the physical Changes of Level.

This study is primarily one of physical and dynamic geology. As it covers such a vast region, only partly explored, errors have doubtless crept in; but the general repetition and later uniformity of conditions, hitherto not brought together for want of the key, and the likeness to those

which prevailed on the continent have emboldened the writer to present this paper, many of the data of which are new or given with new interpretations. There have been many opinions of a generalized character, but few have been accompanied by detailed evidence. On the other hand, there has been a great deal of most valuable information relating to the geology published, without which this paper could not have been written. The key to the dynamic problems was found in Cuba and the southern states; but in Jamaica and San Domingo it could have been obtained just as well, after making the study of the drowned valleys.

The changes in the physical conditions have had an effect on the distribution and preservation of life. To land shells and mammals let us refer.

Long ago Mr Thomas Bland was led to conclude that Florida and the West Indies had been once united, on account of the relation of the land shells. According to Mr Charles T. Simpson, the land shells belonging to the West Indies aggregate 1,700 species. Those of the Greater Antilles (Cuba, Haiti, Puerto Rico and Jamaica) are generically and by minor groups closely related, but the species are mostly restricted to each island. The type of the fauna apparently belongs to the islands, but having relations with Yucatan, Mexico and somewhat with Florida. The fauna of the smaller islands is poorer, and appears to have been derived from South America, having little relationship with the greater islands. The fauna of Bahamas is almost identical with that of Cuba and Haiti. Mr Simpson regards the type as dating back to the early Tertiary period.

Let us see what relation existed between the physical conditions of the West Indian region and the shell-life. At no time since the later Cretaceous period have the Greater Antilles been completely submerged, although they were several times reduced to very small islets, now represented by the higher mountain districts which rise above the Tertiary formations. Consequently the earliest types of shells could have migrated to the unsubmerged lands, and, owing to their habits, found sufficient food and favorable conditions for perpetuating their types. This retreat to small islands was favorable for the specialization into local species. The difference between the types of the larger and smaller islands is not remarkable, for the great physical break between the Virgin islands and the other Windward groups was of such a character as to interfere with migrations. Thus, while the continent was perhaps more than two miles high in that region, the deep depression to sealevel could interfere with migrations. The preservation of related land shells in Yucatan and Mexico is not remarkable. Those regions have suffered the same insulations as the Antilles, thus favoring the perpetuation of old types, for which the less isolated conditions of Florida would afford less protection.

Still there are some common types even in Florida. Accordingly, whatever value there is in the distribution of the shells, there appears nothing unfavorable to the late continental connections set forth on dynamic grounds, although in the great changes of altitude marked effects would be produced upon the species; yet at no time during the high continental elevation was there an absence of low land in some locality of the central continent. Today the bridge between Cuba and Yucatan for a length of over a hundred miles has been swept away to a depth of 7,000 feet, while that between the Bahamas and Florida is gone for a width of 43 miles and a depth reaching to only 2,100 feet.

As Dr Dall's assistance with regard to the invertebrate paleontology has been invaluable to me, so I base my studies of the relation of the mammals to the physical condition of the West Indies on the interpretation of the fauna by Professor E. D. Cope, confirmed by Professor W. B. Scott.

After the early Eocene marine fauna of the *Zeuglodon* type which flourished on the southeastern coast the next mammalian forms known are from the beds which Dr Dall has named the Alachua clays* (from Archer and Mixon's Florida). The bones are thoroughly mixed up, so that no two of the same individual are in juxtaposition. Some tremendous disturbance has come over these graves. The clays occupy depressions and ravines on the eroded surfaces of Eocene and Miocene strata, but they have been removed from the higher grounds, if ever there. From these deposits Dr Leidy determined the following species:

*Rhinoceros* (*Aphelops*) *proterus* (Leidy).
*Mastodon floridanus* (Leidy).
*Megatherium* sp.
*Procamelus* (*Pliauchenia*) *major* (Leidy).
*Procamelus* (*Pliauchenia*) *minor* (Leidy).
*Procamelus* (*Pliauchenia*) *minima* (Leidy).
*Hippotherium ingenuum* (Leidy).
*Hippotherium plicatile* (Leidy).

All of the species are identical or are closely related to the western Loup Fork series according to Professors Cope and Scott; consequently they belong to the very latest Miocene or very earliest days of the Pliocene—in short, to a transition epoch. During that epoch the altitudes of the southeastern parts of the continent were much the same as the present, and it was not connected with the West Indies, which were all submerged except a few small islets. No true Pliocene mammals are known east of the Mississippi river (Cope); consequently we are ignorant of a mammalian fauna on the northern continent, without much expecta-

* Bull. U. S. Geol. Surv., no. 84, by Dr W. H. Dall, pp. 129, 130.

tion of finding such in the remnants of the West Indies. The Alachua mammals lived before the Pliocene elevation. The elevation of the continent by from 8,000 to 12,000 feet produced great climatic differences affecting the food supplies; and this may have led to the extermination of the later Mio-pliocene types and their successors, or these last may have not yet been discovered. At any rate, there is no Pleistocene distribution of mammals to be considered. Dr J. C. Neal,* who was one of the first to make known the occurrence of the Alachua mammals, thought that the animals frequented an ancient lake. Owing to the great denudation during the Pliocene period and the disturbed aggregation and mixing of the bones in eroded post-Miocene hollows, their accumulation would suggest their being washed from their original burial places into ravines or lake depressions while the land was high; but if the clays should be found estuarine then the accumulation must have been a little later, during the Lafayette subsidence of the land. Under any circumstances their occurrence in the Alachua clays means a redeposit of the bones in the Pliocene period and not a mid-Pliocene fauna.

Along the banks of Peace river, near Arcadia, there is a bone bed † with phosphatized rocks about one foot thick lying beneath some 10 or 15 feet of sands and upon a few feet of yellow sandy marl. The following species have been obtained in the river deposits, probably derived from the overlying sands, etcetera. The lists of the mammals were submitted to Professor Cope to arrange their horizons on the geologic scale. It is given by Professor Cope as follows:

*Tapirus americanus*, Pleistocene.
*Elephas columbi*, Pleistocene.
*Mastodon* sp. (not *floridanus*)?
*Hippotherium ingenuum*, (?)
*Equus fraternus*, Pleistocene.
*Bison americanus*, Pleistocene.
*Cervus virginianus*, Pleistocene.
*Megalonyx jeffersonii*, Pleistocene.
*Chlamydotherium humboldtii*, Pleistocene.
*Glyptodon petaliferus*, Pleistocene.
*Hoplophorus euphractus*, Pleistocene.
*Manatus antiquus*.
*Priscodelphinus* sp.
*Emys euglypha*.
*Trionyx* sp.
*Eupachemys* sp.
*Testudo crassiscutata*.
*Alligator mississippiensis*, and a variety of fish remains, including teeth of *Carcharodon*, *Galeocerdo*, *Myliobatis*, etc.

This is a Pleistocene fauna (Cope and Scott). A few species are living, some are peculiar, but the facies is settled. From Ocala and from Caloosahatchee other bones of Pleistocene species, such as *Elephas*, *Equus*,

* Same Bull., p. 128.
† Same Bull., p. 129.

*Bison*, and *Smilodon* (*Machairodus*), have been found. These lists are given by Dr Dall, but my statements are from a recent interpretation by Professor Cope.

In the West Indies, Salterain* states that about the swamps of Ciego Montero, northeast of Cienfuegos, an abundance of bones of the crocodile and the carapaces of the tortoise have been found (these deposits are probably Pleistocene, but the age is not settled). He also states that the *Oryctotherius* (*Myomorphus*) *cubensis* (Pomel) was found in a cave near Matanzas. This animal is related to the *Megalonyx*, a peculiar North American type belonging to the Pleistocene period (Cope). In the Anguilla phosphate deposits three species of *Amblyrhiza*, Pleistocene rodents as large as Virginia deers, were found by Cope, as also some fragments of birds and other animals. One extinct species of *Capromys* (Hutia) has been found in a cave at Trinidad, in Cuba (Chapman), but this may have been more recent than the other species.

It should be remembered that the connection of the Antilles was during the earlier part of the Pleistocene period, with a high bridge between the northern and southern continents. The following subsidence carried the region below the present altitudes to the extent of from 100 to 700 feet, so that even the present islands were very greatly reduced. Whatever effects these changes of level had upon the climate and the modification of food supply, all of the Peace river Floridian mammals, as well as the known Antillean species, became extinct, with one or two exceptions. Indeed, only about 30 per cent of the Pleistocene mammals have anywhere survived to the present day. As the mammalian fauna occurs in beds on Peace river associated with some extinct mollusks, it evidently belongs to the older Pleistocene period, long enough ago to favor local variations in forms, if extinction had not occurred probably during the Columbia or Zapata submergence. Therefore beneath the sea, or under the Columbia or Zapata loams, the Pleistocene mammals lie buried, perhaps in some cases to be discovered where the more recent deposits have been washed away along some river. As Florida did not perpetuate its mammalian fauna, the insular West Indies could not have been expected to. At last, it appears that the known mammalian history casts no shadow upon the inferences as to the physical history of the Antillean continent, and indeed the physical evolution throws light upon the distribution and extinction of the mammalian life.

Of existing species of mammals which are indigenous to Cuba and Haiti, a few words can tell the story. In the two islands there are six species of *Capromys* (Hutia). This genus of rodents is peculiar to the two islands, with three species in each. It is closely related to a Brazil-

* Cited before.

ian type found in the Pleistocene caves. There is one species of *Solenodon* in Cuba and one in Haiti. It is a small Insectivore and considered to be related to a Madagascar type. There is also one Madagascar type of *Iguana* in the West Indies, and two American snakes are represented in Africa (Goode). There is a large number of species of bats. Several early writers speak of Columbus finding dumb dogs in Cuba (Herrara and others). Whether or not a dog, it should be noted that there are wild dogs in Cuba supposed to be the descendants of the domesticated animals run wild. However this may be, from the remarkable appearance of these animals a suggestion would arise that some other blood had been infused in them. The heads of the partly grown dogs seen by the writer had an appearance between that of a small pig and a bear's cub, and the animal is remarkably clumsy.

The introduction of the few small animals named into the West Indies appears to date from the Pleistocene elevation and modified during the succeeding epochs, being capable of surviving the changes of level and the contraction of the islands to small size. The mammalian life of Florida has been a recent introduction since the Columbia submergence and subsequent reëlevation.

## Summary.

The restoration of the Antillean bridge between the two Americas is based on the discovery of submerged system of drainage valleys, which now constitute fjords, and their relationship to the buried valleys along the coast of the continent and islands. The valleys of the mountains and these extending across the coastal plains are all the result of atmospheric erosion, but their lower reaches are very broad and deeply buried by late accumulations on account of recent subsidences. These valleys are compared with the fjords crossing the coastal plains and shelves to the abysmal depths. The geomorphy is exemplified in the effects of erosion, and this is modified by the altitude of the land and by the epeirogenic or gentle continental undulations of the earth's crust without obliterating the forms of the valleys, which, although drowned, increase in magnitude in their descent and receive tributaries from all directions. These recognizable fjords or submerged valleys are so numerous that if errors of observation occur in some of the data the general results are not impaired. Many of them are traceable to depths of over two miles along the Atlantic, Gulf and Caribbean coasts. The measurements of the fjords give data for calculating the late continental elevation of the region. From the application of the quantitative movements it becomes apparent that the continent stood as high as the fjords are deep, less some correction for unequal subsidence of the continental

region. Accordingly it is concluded that the Antillean bridge stood at from one and a half to two and a half miles above the present altitudes of the plains that now form the islands, with their mountains relatively somewhat lower than at present. The floors of the Mexican gulf and the Caribbean sea were then plains, and there seems to be strong reason for inferring that these plains drained into the Pacific ocean.

The formations out of which the valleys are excavated belong mostly to the more recent geologic periods, and are generally but little disturbed. From the determination of their age and that of the materials filling the buried valleys, it has been found that there have been two epochs of great elevation, namely, in the Pliocene and in the Pleistocene periods. Between these there was a subsidence of such depth as to drown the continental coastal plains and reduce the West Indian region to very small islands, with (probably) a shallow connection between the Atlantic and the Pacific oceans. The mid-Pleistocene depression was not quite so great as the earlier, and there was probably a strait connecting the two oceans. Since that time there have been several oscillations of minor degree, with the formation of many small coastal canyons and the elevation of terraces and coral reefs.

The Central American barrier did not sink to the depths of the Antillean seas in the great subsidence, but this has been further raised in part by the epeirogenic movements and thrown into a great barrier by orogenic movements and volcanic action.

The Neocene and Pleistocene mammalian fauna suffered from both the changes of climate, passing from the tropical to the almost arctic, and the consequent changes in the food supply, and the extermination was completed by the depression of the broad areas below the sea.

This study establishes the great mobility of the earth's crust, and the application of the methods reaches far beyond the region investigated in this contribution and opens many new problems in dynamic geology.

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NOTE (see page 118).—A study of the slopes of the drowned valleys might have been desirable, but it should be noted that their mean slope could not have been compared with that of existing rivers except those of mountain plateaus, for most of the valleys of the eastern part of the continent are buried in their lower reaches by recent accumulations, and therefore do not represent their true slope of erosion. In the denudation of the high tablelands, even when composed of loose materials, the valleys deepen slowly, the great excavations being made at the points of sudden descent. Here the deep valleys are rapidly elongated, their length partly depending upon their age. The analogy between the slopes of the drowned valleys and that of the valley of the Colorado river is close, but comparison could not properly be made with one like that of the Mississippi river.

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# EVIDENCES AS TO CHANGE OF SEALEVEL

BY N. S. SHALER

*(Read before the Society August 14, 1894)*

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## Introduction.

The great importance of changes in the distribution of land and sea has in a general way long been recognized. Of late years interest in the question has been increased by the studies of geologic climate which have been undertaken, as well as by the extension of our knowledge concerning the movements of faunas and floras over the submerged and emerged portions of the earth's crust. From the time of Strabo down to the present day all those who have looked intelligently on shoreline phenomena have recognized the inconstancy in the relations of sea and land. Almost all the students of such phenomena have, in their thinking, made the assumption that the changes in the positions of the shoreline were due to the simple process of up or down movement of the crust where the changes in elevation have occurred. Strabo saw, and briefly indicated in his writings, that we must take into account not only the swayings of the land itself, but those movements of the deep-sea bottoms which, by displacing the ocean waters, might cause them to flow over or recede from the land masses. From the time of this illustrious geographer to near the present day his admirable suggestions as to the movements of the ocean floor were neglected. Here and there an author has

briefly referred to the influence of such swayings of the crust beneath the thallassal areas.

## Conditions and Actions affecting Sealevel.

### *SYNOPSIS OF AUTHOR'S PREVIOUS VIEWS.*

Some years ago I undertook to present* in a formal way a list of those actions which are or may be concerned in the changes of level of the coastline. As the points therein discussed are of importance with reference to the matter which is to be taken up in the following pages, I venture to recapitulate them as follows:

Although the direct up and down movement of the land is the most obvious because the simplest possible explanation of coastline changes in level, it is doubtful whether it is the prevailing or even the frequent mode in which these alterations of height are effected. Occasionally, by the faulting of blocks of strata or the accumulation of volcanic matter below a crater, or even by the injection of dike materials in crevices which do not attain the surface, local vertical movements probably occur, but in most instances the swayings of the earth must be regarded as widespread phenomena connected with the tolerably steadfast process by which the continents go upward while the sea-basins deepen. In other words, the sections of the crust involved in the movement which affects the coastline are tilting upward on the continental side and downward beneath the sea. The movement is like that of a lever with a variable fulcrum point—a point of bearing which itself may be subjected to some dislocation. In this movement about a variable node, which we must conceive as taking place on the continental slopes from the centers of the land areas to those of the sea, it is evident that the shoreline may have a variable position. It may by chance, though probably seldom, occur that the contact of sea and land is just over the node, in which case the rotative movement, so far as it determines the position of the coastline, may be imperceptable. But if the neutral point is seaward, the effect will be to lift the land above the water. If, however, the fulcrum be to the landward of the coast, the same movement would cause the sea to gain on the land. Thus, so far as the changes of coastline are concerned, which are brought about by the normal downgoing of the sea-floors and uprising of continental areas, three different conditions may come from the same action: that of no motion of the coast, that of uprising, and that of downsinking of the land.

The above simple considerations show very clearly that the phenomena of elevation of continents as regards the action on shorelines is much

* Proceedings Boston Soc. Nat. Hist., vol. xii, October 7.

more complicated than it is generally assumed to be. We are, however, as will shortly appear, but at the beginning of the entanglement of actions which affect the plane of the sea in relation to that of the land.

### *SUBMARINE FOLDS.*

Strabo noticed the probability that changes in the level of the ocean-floor were likely to affect the incursions or excursions of the seas. Our better knowledge enables us to note the fact that the topography of the sea-bottom leads us to discern something as to the movements which bring about vast displacements of water. The recent advances in the inquiries concerning the form of the lithosphere beneath the oceans show us pretty clearly that the larger part of that area is occupied by broad, rather gently sloped ridges which in a general way, except for the absence of mountainous relief, resemble the continental upfolds. I have elsewhere* suggested that these folds of the deep are in effect unemerged continental masses; that a continent is one or more of these folds, generally a plexus of them, which has attained the realm of the air and in that realm has been subjected to the erosions and consequent dislocations which give rise to the characteristic topography of the great land areas. For the present we are concerned with another influence which arises from these submarine foldings, namely, the general changes of ocean-level which are brought about by their formation. The variable depths at which these undulations of the deep sea-floors lie, as well as what we know concerning the bathometric conditions of formation of the stratified rocks, make it reasonable to suppose that these unemerged folds are subject to swayings and in general to an upward growth, such as has presumably brought certain of them to the state of the continents. In the paper above referred to I have noted the fact that certain topographic features, such as the peninsula of Florida, appear to be folds of the nature referred to, which in the process of their elevation have recently been raised above the sealevel.

Although it is eminently probable that the elevation of the submarine folds is attended by a greater or less downward motion of the troughs which lie between them, it is not at all probable that in the movement the conservation of areas is anything like perfect. It is more likely, indeed, that at one time in the earth's history the effect has been to lift the general sealevel in relation to the continental masses and at another to lower it. When, in the process of upward growth, the submarine continent comes to be in part subaërial the further swayings of the mass will be yet more effective in changing the level of the ocean. Thus, if North America should remain undisturbed while the Eurasian mass underwent

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* Bull. Geol. Soc. Am., vol. 5, December, 1893, p. 203.

an elevation, on the average, of 500 feet, the effect would be the elevation of the sealevel by a considerable amount—by an amount probably sufficient to have a distinct geographic value along its shores.

The considerations just presented enable us to see that the changes of level of shoreline at any point depend upon the alterations in the form of the lithosphere, which are taking place all over the earth's surface, and that the equation which determines the conditions at any point or time is of a rather complicated nature.

### *ATTRACTION OF CONTINENTAL MASSES.*

In addition to the foregoing influences, there are others, though relatively minor, which have to be taken into consideration. As has often been noted, the attraction of the continental masses, or even of the great mountain systems, may serve to elevate the sea to a considerable height above its average plane along particular shores. Thus the water at the head of the bay of Bengal is much above the level which it has on the shores of the islands in the middle of the Pacific. Thus, with the growth of a great mountain-mass on the margin of a continent, the sea may be drawn upward to an extent which may have measurable geographic effects. It would be possible in this way to effect a difference in heights, which, in the case of isthmuses, as at Darien or Suez, would overflow the low lying barrier.

### *GLACIAL ACCUMULATIONS.*

Yet, further, we note that the accumulation during glacial epochs of great ice-masses about either pole would in two ways serve to change the ocean plane—by the withdrawal of water from the ocean and by the irregular attractions of a gravitative nature which the masses would exert on the seas. If, as J. Adehemar has pointed out, the ice-cap were accumulated about one pole to the thickness which is sometimes estimated as having occurred in the last glacial period, the displacement of the earth's center of gravity might amount to half a mile or more. Although this estimate has little value in a quantitative way, it is evident that ice-cap displacement must be reckoned as among the considerable influences which from time to time affect the equation of causes which determine the level of the sea.

## SHORELINES.

### *GENERAL OBSERVATIONS CONCERNING THEM.*

The foregoing considerations serve to prepare the observer for the study of shorelines by showing him how many are the influences which serve to make variable the vertical station of the sea. A very little observation

along almost any shoreline will make it evident that the position of the sea is subject to continued alternations, which are more or less marked in the physical features of the lithosphere above or below the water. Although a good deal has been written concerning the nature of the evidence of such changes, there is, so far as I am aware, but little of critical value, except the work of G. K. Gilbert, based upon the study of ancient lake Bonneville. I propose, therefore, in the following pages briefly to consider certain criteria which may be applied to the study of shorelines with reference to their oscillation, exemplifying the work from a study of the coastlines of North America, principally that formed by the Atlantic ocean, together with some references to the present condition of other coastal districts.

### *DEFORMING AGENCIES AFFECTING SHORELINES.*

*Pluvial Erosion.*—Assuming that a sea-bottom fold attains the surface of the water in the manner of recent upliftings of that nature, such as are afforded by the peninsula of Florida, it is evident that the first deformation which occurs is that which is accomplished by the action of waves, combined with that of tidal and other currents. Together with this action goes the work done on the emerged part of the elevation by the rain and wind. These two groups of actions—the marine and the atmospheric—work to different ends and in a diverse manner. In general it may be said that the atmospheric wearing tends to lower the emerged area at a very variable rate, depending as it does upon the amount of rainfall, the extent to which the uplifting actions prevail against the erosion and the character of the materials upon which the pluvial waters operate. Given a sufficient rate of elevation, whether it be that of the fold in general or of mountains originating on its surface, the effect is to diversify the reliefs by creating a system of ridges and valleys.

*Marine Erosion.*—The effect of the marine erosion is brought about by a horizontal attack along the shores. Along that zone the energy gathered into the waves—it may be over thousands of square miles of water—can be applied to each mile of length of coast. In the case of a newly emerged fold the shorelines are normally straight or with slight curves, due to the irregularities of its surface, irregularities which are generally slight, so that the measure of a wave and tidal wearing is likely to be nearly equal on each mile in length. Thus the normal ocean erosion differs in a striking way as regards its mode of action from that which is brought about by atmospheric agents; yet further differences may be noted in the secondary effects of oceanic degradation. In them we find that the waste from the shore tends to enter the chance embayments along the line, and by filling them to convert what may have been origi-

nally an indented margin to a straight beach. If an emerged fold remained with no change in elevation after it had attained the surface, the normal result would be the gradual obliteration of the relief by the inward march of the marine bench, ending with the formation of a benched-off shoal. It is evident that with a given elevation of the original fold the character of the surface from the center of the land to the center of the neighboring seas will depend upon an equation in which there are four factors—the original height of the surface, the rate of downwearing on the land, the rate of inwearing of the sea, and the rate of accumulation of the detrital shelf off the coast. Thus in a newly emerged fold the bench-work of the sea and the corresponding land scarf will be small, as will also be the submarine shelf, which is the product of the land waste and of the organic matter originating in the sea which is deposited upon that accumulation. It is evident also that each of these groups of agents is subjected to innumerable slight variations. The emerged folds will not be homogeneous in their constitution, the rate of land-wearing will vary, according to the distribution of the rainfall and the streams to which it gives rise, and the growth of organic material in the sediments off the shore likewise varies at different points. We may, however, for the present neglect these innumerable modifications of the factors and note merely the conditions, in a somewhat ideal way, of our supposititious newly emerged fold. We see that the geologic work done upon it leads to a transfer of its rock matter by the streams and waves, either into the state of solution or in the immediately detrital form, to the submarine shelf.

*Oscillations.*—Owing to the very numerous causes which lead to changes in the elevation of shorelines, the simple condition of an emerged fold of the lithosphere, which does not afterward change its position until it attains the stages of a benched-off shoal, is practically unknown. All areas the history of which I have been able to ascertain show the result of numerous oscillations in the relative level of sea and land. Even in the case of Florida, as I shall afterward note more in detail, there are reasons to believe that the fold has oscillated with reference to the sea through a range of near a thousand feet since the time when it first pushed the waters apart. In these vertical swayings it is easy to see that the zones of action overlap each other. In a process of elevation the coastline, followed up by the zone of atmospheric erosion, will pass out on the depositional shelf. In periods of subsidence the coastline, followed by the depositional shelf, will invade the zone on which the record of subaërial actions is written. In fact, along any shore-belt, counting as such the zone within which the coastline has swung, it becomes a matter of first importance, though one of exceeding difficulty, to determine the

share in the expressions and structure of the surface and underlying rocks which has been brought about by the several oscillations of the sea. It is to this interpretation that we shall now give our attention.

Accepting the fact, which is abundantly proved by the study of shorelines and by evidence which is from day to day increasing in amount and definite value, that seashores are subjected to frequent oscillations of level, we may first take into account the point that the lesser changes of level are much more frequent than the greater, or, in other words, that along any coastal belt the improbability of the shoreline having within a certain time been at any horizontal plane increases with its vertical departure from the present sealevel. Inasmuch, however, as the lands are prevailingly rising and the sea-basins deepening in the manner before noted, the likelihood that the sea within a given time has had its plane at a given height above the present position is greater than that it has been at a given depth below that level.

Another statement of this proposition may be made as follows: On any coast the probability that the shoreline has been farther out to sea than it now is is less than the probability that the line has been farther inland in the measure to which elevating forces, that serve to maintain the land against the erosion to which it is constantly subjected, have acted.

*Results achieved by deforming Agencies.*—These considerations serve to show us that the farther we go above the sealevel the less likely it is that we shall find definitely ascertainable marks of marine action. The probability that slight oscillations exceed those of great amount, and the likelihood that the lands will continue to rise, together with the rapid way in which the erosive agents of the atmosphere attack the sea-made topography, tend to destroy the evidence of ancient marine action.

The normal result of the above described actions is to develop next the shore, both to the seaward and landward, a system of erosion and construction planes all sloping toward deep water. Where the process is long continued there may be relatively little difference in form exhibited by this surface, either below or above the water. There are, however, in all cases certain distinctions between destruction and construction planes. The former usually retain at least a substantial shadow of their drainage system, while the latter show when they have been elevated, and less distinctly, by soundings, a peculiar undulating topography, such as is produced by submarine conditions, but never by the land waters.

*Mountain-building.*—If continental shores had the simple history indicated by the statements made above the interpretation of coastline changes would be much simpler than it is. In most cases, however, a number of perturbing influences enter into the action, of which the formation of

mountains is the most considerable. The evidence we have in hand points to the conclusion that ordinary mountain-folding, if not limited to the seashore, prevailingly begins when and where a tract of country has been subjected to the erosion and transference of materials, such as occurs in a coastal belt. I have already noted* how considerable is the evidence from the distribution of mountains going to show that they do not originate on the deep-sea floors. It is worth while also to note the fact that where mountain folds involve a number of formations the evidence goes to show that interruptions of deposition have occurred such as are explicable only on the supposition that the region in which they developed was at or near a coastline. It is easy to see that the development of mountains next the shore necessarily tends to destroy the marks of ancient sea-margins. This result is accomplished in two ways: In the first place, the irregular uplifting of the surface will necessarily throw the planes of the old shore out of their original horizontal attitude, while the intensified erosion due to the institution of the new steeps hastens the destruction of the old marine benches.

## Criteria indicating higher Sealevel.

### *MARINE CLIFFS AND BENCHES.*

The criteria by which we may determine the former presence of the sea at a higher level than it now has may best be judged by the study of existing shorelines where the coast is unprotected by detritus, so disposed as to form a barrier to wave-action. There are two elements usual in the topography of such a coastline, each of great but diversely enduring value. These are the marine scarf or cliff and the corresponding greater or less bench, where the materials disrupted by the waves which are not dissolved in the water are accumulated. When the coastline is elevated the atmospheric processes rapidly operate to destroy the cliffs. With most rocks a few thousand years will serve so to break down the steeps and to convert them into taluses of a relatively low angle that even the eye most practiced in the interpretation of such phenomena may fail to detect in them satisfactory evidence of marine erosion. So far as my observation goes, the most enduring evidences of marine action are the detached elevations ("monadnocks," as they have been termed by Professor Davis), which were islands in the ancient seas at the time when the waters beat at or near their bases.

### *MARINE CAVES.*

Next in lasting value, though much less enduring, are marine caves, which in favorable positions sometimes penetrate a considerable distance

*See this Bulletin, vol. v, p. 203.

from the surface, and being well placed to avoid erosion, they endure, as fresh-water caverns may, until the downwearing surface penetrates to their level.

### DETAILED DISCUSSION OF CRITERIA.

*Danger from imperfect Discrimination of Phenomena.*—Both these evidences of ancient marine steeps are likely to be confounded with other phenomena. Isolated mountains may owe their relief to certain elements of resistance to decay which their materials afford that may not be apparent on inspection or even after careful laboratory study. Various parts of the valley of the Mississippi abound in buttes or knobs which I at one time regarded as evidences of marine action. A more careful study of these steep faced eminences has led me to the conviction that in many cases they are due to differential erosion, soft beds at their base dissolving away, and the firmer overlying rocks, when broken to pieces by their downfall so as to expose a large surface to decay, likewise being borne away by the surface water. In yet other cases, where the frost breaks a portion of the material into the form of sand, the grains are driven by the wind against the escarpment in such a manner as to bring about a rapid process of erosion, such as is plainly visible along the cliffs of the Millstone grit in eastern Kentucky.

In the effort to interpret the deserted shorelines of the Atlantic coast by the study of the ancient marine cliff I have been so far baffled by the process of their ruining, combined, it may be, with dislocations of position due to differential movements of the surface, that only here and there does the evidence seem to me of a conclusive or even of a probable nature.

*Persistence of the submarine Shelf.*—The innermost part of the submarine shelf, that which is composed in most cases mainly if not altogether of débris from the neighboring steeps, is in many cases, though originally a less conspicuous, a much more enduring feature than the scarfs. Owing to its approximately horizontal position, this comparatively inconspicuous feature is often less effectively attacked by the agents of decay than the firmer rocks of the ancient cliffs. It yields readily, of course, to stream-action. It is apt to be covered over by the talus derived from the decay of the cliffs, but the topographic indication, as well as that which may be had from the form and disposition of its débris, long remain of value.

*Barrier-beaches untrustworthy as Criteria.*—Along an old shore, one where the sea for a considerable time has lain against the same part of the land, and therefore has been able to bring its construction bench to near the surface of the water for a considerable distance from the shore, we are likely to find barrier-beaches with their concomitant hooks, tidal deltas and other peculiar topographic forms due to migrating sands. Although

on the elevated coastlines to the west of the Dismal swamp, in Virginia and North Carolina, I have found some traces of these barrier features, and although I have suspected that the remnants of such topography accounts for the formation of some high lying swamps in certain of the southern states of this country, it is evident that this group of coastal structures is not to be trusted as evidence of old shorelines. Their prevailing absence where they might be fairly expected to occur is perhaps due to the fact that they are composed of almost pure sand, and thus do not readily become occupied by vegetation. We readily perceive that wherever along the coastline such sands cease to be fed from the sea they are speedily dissipated by the wind. The same fate probably overtakes them when they are elevated above their original plane of the coastline on which they were formed.

*Character of detrital Shore-beds.*—The condition of the fragments which make up the detrital beds of sea-margins affords an important indication which may be used in determining elevated beaches. Where there are pebbles which are the product of wave-action, the condition of the fragments affords an excellent basis for discrimination. The peculiar movement of the detritus on a shore where rolling beaches occur brings about the formation of sub-ovate pebbles, such as I have never been able to find formed by any other mode of action except that used in the revolving drums which serve for making boys' marbles. The nearest approach to the result is attained by the subglacial streams which often produce well rounded bits, yet the most of these differ notably from true wave-worn pebbles.

*Remains of marine Scarfs.*—Where it is possible to find a trace of a scarf, however obscure, provided the remains be at coincident heights for a considerable horizontal distance and along with this evidence remains of a shelf containing rounded pebbles, the presumption that the indications are those of a coastline is very strong. If by chance remnants of caverns can be found in the escarpment, the association of proof becomes yet stronger.

*Exposed offshore Deposits.*—It might be supposed that wherever in relatively recent times a beach now elevated has been formed the surface of the earth below its level would retain some indications that it had been beneath the water. It might reasonably be expected that a submergence which had endured long enough to permit the formation of characteristic beach accumulation would have sufficed for the formation of a tolerabl enduring marine deposit lying offshore.

At the outset of my studies of the elevated beaches of the Atlantic coast, the remains of which are of a rather fragmentary nature, I was led to doubt the verity of the indications by the absence of these marine

deposits from the surface of the lower lying lands. To test the matter I resorted to the country lying on the west and south of lake Ontario, where the well preserved Iroquois beach indubitably proves long continued sojourn of the waters at a considerable height above their present level. I found that below the plane of the beach the general surface of the country showed no distinct indications that it had been submerged. In fact, I was unable to find any criteria which would enable me to discriminate the areas below and above the ancient sea-margin. It must be believed that where the submergence has endured for a long time a certain amount of sediments would be laid down in the offshore district, and that the period required for the formation of such a beach as that last mentioned should have brought about a considerable accumulation of clay. It seems, however, likely that in a few thousand years of exposure such clay deposits would by the down bearing action of the rainwaters be carried down into the earth or washed away into the streams. Thus in the sandy and gravelly areas of southern New England it is here and there the custom to improve the roads by covering their surfaces with glacial and other clays. Experience shows that such a coating, originally several inches in thickness, will in the course of five years completely disappear. Even where marine deposits contain fossils the removal of the clay element would lead to the rapid decay of all organic remains. It seems to me that in this way we may account for the disappearance of relatively thin offshore deposits made below the plane of ancient sea-margins.

## Criteria indicating lower Seashores.

### *SUBMERGED ESCARPMENTS.*

The evidence that the shore has been farther to the seaward, that is, at lower levels than at present, is unfortunately of a very obscure nature. Here and there submerged escarpments lying below the plane of wave-action are traceable under conditions which make it likely that they are not due to fault-action, but are indeed the products of wave-work. Here and there steepenings of the slope on the surface of the continental shelf may afford grounds for inferences of some value.

### *FLOODED VALLEYS.*

Thus far the only proof of value, and that happily of much weight, is afforded by the flooded valleys which intersect, as we shall see hereafter, the larger part of continental coastlines. It seems to me unquestionable that where a coast exhibits a system of valleys affording drainage to large rivers, the basins of which have been the seat of abundant and recent

degradation, and where the rivers in place of having normal deltas enter the sea by estuaries, the shapes of which can only be explained by the supposition that the margins of the marine reëntrant are the steeps of the old river valley, we are justified in assuming the subsidence of the land.

It is true that there is some difficulty encountered when we come to apply this topographic index to glaciated districts. Thus in the fiord zone, where the plane of the sea cuts the glacially worn, hard rocks, we may always assume that the ice-streams could have excavated the channels for some distance outward beyond the point where the sea, if freed from the ice, would have come in contact with the land. It is very likely, indeed, that much of the fiord topography was due to ice erosion, accomplished below the ocean level. Where, however, the valleys are broad, in the manner of that of the Saint Lawrence below Montreal and in other similar instances, the most reasonable supposition generally is that the indentation is due to the flooding of a river trough. This supposition can often be verified by the fact that rivers occupying preglacial channels converge in a normal digitating manner toward the axis of the valley. This evidence is beautifully shown in the case of such flooded valleys as that of the Chesapeake.

## Changes in Altitudes of the Shores.

### *NORTH AMERICAN COASTS.*

*General Statement concerning Them.*—On the basis laid down in the foregoing statements I shall now proceed to note some steps in the process which it seems to me we are prepared to take in the general interpretation of the changes of elevation which have occurred in the recent geologic ages along the coast of North America, and incidentally on the shores of the other continents. In this task I shall not undertake to present in any detail the results of certain studies which I have of late years made while in charge of the Atlantic Coast Division of the United States Geological Survey, and this for the reason that to set forth my observations, though they are as yet incomplete, would require excessive space. In this writing my aim is merely to state certain general conclusions, which appear to me to be well supported by the topography of the shoreline, along with a few notes drawn from observations on the land area.

*Isthmus of Darien to Florida.*—Beginning the consideration of this continent with the isthmus of Darien and proceeding northward we observe that the coastline shows little evidence which can be interpreted as indicating flooded valleys, or, in other words, a recent depression of the shore, until we reach the northern border of Mexico. Thence along the

eastern side of the continent to the northward the signs indicating recent downward movement appear to me evident and to indicate a progressive subsidence of a somewhat uniform nature to near the pole. Reëntrant valleys begin to be indicated along the Texan shore. At the Mississippi we find proof that this great valley has recently been lowered, so that the sea penetrated far into the land, perhaps to and even beyond the junction of the main stream with the Ohio. In Mobile bay, as well as in one or two reëntrants to the eastward along the Gulf shore, there are similar evidences of subsidence.

*Floridian Peninsula.*—In the peninsula of Florida we have a geographic feature which throws much light in diverse ways on the general history of the Atlantic coastline. I have elsewhere noted* that Florida appears to be a submarine fold, the summit of which is at the present time elevated to less than one-tenth of its total height above the surface of the sea. There are reasons, however, for believing that the whole peninsula has recently stood much higher than at present. The evidence on this point is as follows:

In the first place, the coastline exhibits a number of flooded valleys, of which that of the Saint Johns river is the best preserved and most conspicuous. There are several other vales which recently were embayments of the sea that have of late become effaced by detrital deposits and swamp accumulations. Some of these channels along the west coast, which are now completely filled by a sand plain formed in a very late minor oscillation that reduced the peninsula to very small dimensions, are evidently of considerable depth, as is shown by excavations made to obtain the phosphate nodules which were washed into them by marine action. It is tolerably evident, indeed, that if the recent deposits here alluded to were removed the surface of the Cretaceous and Tertiary beds would be found deeply scarred by gorge-like valleys.

Another evidence indicating the recent elevation of Florida to a considerable height above the sea is found in the fact that on the eastern and western shores of the northern half of the peninsula there come forth from a considerable depth beneath the sea great springs of fresh water. One of them, nearly off Saint Augustine, is formed by the discharge of such a volume of water that where it rises through the heavier marine fluid it forms a slight elevation, from which the outsetting stream is so strong that, according to trustworthy reports made to me, a boat has to be rowed with some energy to attain the center of the disk. As there is no way in which we can account for the excavation of the subterranean channels through which these waters course to their present exits beneath the sea except by the supposition that they were made as caverns

*See Bulletin of this Society, vol. 5, p. 206.

in the limestone rock with all their parts above the erosion baselevel, we have to suppose a considerable subsidence to account for these inverted siphons through which the rainwater courses to the sea. I am not aware that any soundings have been made which serve to show the depth of the sea immediately over these submerged cavern mouths. It is, indeed, not likely that such soundings would give evidence of value as to the original horizontal plane of the exits, for under the existing conditions the streams would tend to cut away the roofs of the caverns near the mouths and to fill in the floors at those points with débris, so that the exits may have worked upwardly for an unknown height. Therefore these submarine springs, as with like phenomena along other coastlines, while indicating the downsinking of the land, afford no useful gauge as to its amount.

There is yet another set of facts which serves to show that the peninsula of Florida has recently stood at a much greater height than it now occupies. The wells which have been bored in the district, some of which have attained the depth of more than 1,000 feet, show that the water of deposition—that is, that of the seas in which the marine strata were formed—has, to the depth of 800 feet or more, been almost altogether displaced by rainwater. It does not seem to me possible to account for this leaching out of the construction water except on the supposition that the area has recently been much higher than it is at present. It is true that the time of this elevation cannot be determined, but the age of the strata affected seems to indicate that the event occurred in comparatively recent Tertiary time.

It seems to me that the three groups of evidence above noted clearly establish the fact that along the Floridian portion of the coastline there has been a recent subsidence, the depth of which is to be measured by hundreds of feet.

*Florida to Delaware Bay.*—North of Florida and thence to the southern limits of the ice-sheet of the last glacial epoch the evidence from flooded valleys, though as far as Hatteras it is more or less masked by barrier-beaches and swamp accumulations, is unmistakably clear. None of the rivers exhibit deltas, except slight accumulations at the head of their reëntrants. All of them are flooded for a considerable distance from the open sea. In the Dismal swamp district, moreover, as I have noted in a report on that district,* some of the streams within the morass have their existing bottoms much below the level of the neighboring sea-floor.

*Delaware River.*—Delaware river is the last stream the mouth of which is south of the glacial field. It is therefore the most northern of the Atlantic coast rivers where the effects of flooding due to subsidence are

* Annual Report of the United States Geological Survey, 1890, p. 329.

not complicated with the scouring action of ice. Although this flooded estuary has doubtless had its bottom considerably elevated by sediments imported into it during and after the Glacial period, we may by prolonging the slopes of the land on either side interpret its original depth in an approximate way. From such evidence it seems likely that the floor of the original stream-bed which occupied the valley was 200 feet or more below the present bottom.

*Delaware River to Cape Cod.*—To the north and eastward of the Delaware, as before indicated, the process of glacial excavation has somewhat confused the record of submergence made by the flooding of valleys; yet the evidence seems to me to indicate an increase in the recent average downsinking of the continent as we advance along its eastern margin toward the pole.

The valley of Hudson river is flooded as far as Albany, and although it is considerably clogged it has, owing to the peculiar condition of its headwaters, but little filling due to delta-action.

The channel of Connecticut river, owing apparently to the fact that it was the pathway of a great subglacial stream which was heavily laden with sediment, is overfilled with the detritus of its terrace deposits.

Farther to the eastward the valley of the Thames, in Connecticut, though somewhat affected by glacial erosion, appears to be in form substantially what it was just before the advent of the ice. In it the flooding is conspicuous and extensive. So, too, in Narragansett bay we have a river basin which appears to have been mainly shaped by the action of land water, which has been very extensively flooded.

*Cape Cod Peninsula.*—The peninsula of cape Cod and the remnants of an ancient land preserved in Block island, the Elizabeth islands, Marthas Vineyard and Nantucket show us that down to relatively late stages of the Tertiary the part of the shore on which they lie was very much higher than at present. Although the old surface of these areas is to a considerable extent hidden, it is possible to trace a system of valleys partly clogged by drift, but frequently with their mouths considerably flooded in a way that indicates recent submergence.

It now seems to me tolerably clear that Vineyard sound was the seat of a considerable stream, the divides of which are partly preserved in the ridges of cape Cod, the Elizabeth islands and Marthas Vineyard. Another similar valley occupied by a considerable stream is now flooded by the waters of Buzzards bay. The obliteration of these ancient river-systems seems to be much more complete than is the case with those between the southern margin of the ice-front and Florida.

*Cape Cod to Bay of Fundy.*—North of cape Cod it has not as yet appeared to me possible to discriminate the measure of flooding of the valleys

due to subsidence from that brought about by glacial erosion. A careful study of numerous tributaries of these flooded valleys has, however, convinced me that the average amount of erosion accomplished in the last ice-time on the general surface of the country as far to the northward as New Brunswick did not exceed 50 feet. It is possible, however, that in the axes of the main streams the ice, owing to its deeper cutting, did more extensive work. The impression, however, left upon the observer is that these streams owe their present depth and penetration of the sea much more to downsinking than to the erosion of their channels by ice.

I have endeavored to ascertain whether the channels of the streams to the north of cape Cod are prolonged in depressions below the level of the sea in the manner of the well known instance of the Hudson river. Although the soundings give indications that such is the case, the evidence which they afford is not as yet sufficiently clear to warrant any distinct statements. It may be said, however, that the topography of the bay of Maine, so far as the shape of its bottom is known, is better to be explained on the supposition that it is a land surface which has recently been depressed than in any other manner.

*Bay of Fundy.*—The bay of Fundy by its form as described by its shorelines, by the normal convergence of its rivers, and by the shape of its bottom, as far so that is known, appears to be an extensively flooded valley, the baselevel of which was 500 feet or more below the present plane of the sea.

So, too, in the eastern extremity of the peninsula of Nova Scotia and the island of cape Breton we have evidence of extensive valley-flooding.

The Gut of Canso seems to be the valley of two streams which headed against each other, the common trough having been considerably modified by glacial action.

The extensively digitated reëntrant known as Bras d'Or, which I have examined with some care, must be reckoned as a river valley, somewhat modified by ice-work, which has been flooded to its headwaters.

*Gulf of Saint Lawrence.*—The gulf of Saint Lawrence and the narrower part thereof, extending as far as Quebec, seems to me explicable in no other satisfactory way save by the supposition that it is a flooded basin, the general topography of which was determined during a period of elevation. I think that this explanation is doubtless true of the wedge-shaped indent from Gaspé peninsula to the head of tidewater. The field of waters commnoly termed the Gulf presents certain puzzling features which I shall now note.

These peculiarities consist in the numerous islands, scattered over the Gulf, which have very precipitous sides. Entry island of the Magdalenes, Bird rocks, Roche Perce island and the northern coast of Anticosti

island have steep cliffs, with very little talus materials beneath their submarine bases. Some of these cliffs, as, for instance, those on the northern side of Anticosti, indicate a very great amount of shore erosion. Those last named could not well have been brought into their present shape without the wearing back of the shore for the distance of some miles. Therefore, if we supposed that the formation of these steeps was due to the work of the sea since it stood at its present level, we would have to reckon on a great lapse of time since the last downgoing, and would be unable to class the movement with those which have taken place in the geologic yesterday along the more southern shore. Owing, however, to the prevailing absence of talus material at the base of these cliffs, I am disposed to regard them as due to erosion, accomplished during some preglacial age. They may, indeed, be escarpments formed subaërially, which have been but slightly modified in form by marine action. It is manifestly difficult to explain the origin of these steep faced islands on the supposition that they are due to marine work and at the same time regard the basin of the Saint Lawrence gulf as a flooded valley; yet I do not think that the reconciliation of the views is impossible. It does not seem to me well, however, to discuss the matter further in this paper.

*Labrador.*—The fiords of the Labrador coast, though they constitute deep reëntrants, so far as we yet know, may be due to glacial excavation. As I have not seen the shores of the peninsula beyond the straits of Belle Isle, and as the topographic evidence is not clear, I shall not undertake to discuss the question of flooding along this part of the shore.

*Arctic Shores.*—In what may be termed the Arctic section of the Atlantic coastline of this continent the general topographic evidence is clearly in favor of the hypothesis that the land has been subjected to a great lowering, and that the land basin and valley topography is prolonged beneath the sea for a great distance beyond the present shoreline.

Hudsons bay and the strait which connects it with the Atlantic has a form which is not readily to be explained by the hypothesis of local downwarping, but is better accounted for on the supposition that it is a flooded basin. The marine trough which separates Greenland from the American continent appears rather as an invaded valley than an original strait, and the divisions between the numerous islands lying between Greenland and the mainland appear to be best explained on the supposition that they too, though perhaps somewhat affected by ice-action, owe their existence to river-work.

Although it would be perhaps reasonable to adduce the hypothesis of differential warping to account for some part of the entanglement of sea and land along this part of the coast, it seems to me unreasonable to suppose that the assemblage of facts can fairly be thus explained. Taken

in connection with the evidence afforded by the better known southern parts of the shore, with its flooded valleys and submerged forests, it seems to me that the only tenable view is that of recent and extensive subsidence, perhaps amounting in the Hudson Bay district to 1,000 feet or more.

*Pacific Coast.*—On the western coast of North America a comparative absence of considerable river valleys makes the interpretation of the coastline movements more difficult than on the eastern shore. Moreover, the streams which exist in that field flow from a country which is as yet not far advanced toward baseleveling, and therefore have their channels in most cases so steep that the penetration of the sea, with a given amount of downsinking, would be much less than on the Atlantic slope. Furthermore, the studies of recent changes of level along the Pacific have afforded as yet but little evidence, such as raised beaches or submarine forests. In a word, the problem, so far as this shore is concerned, is not ripe for discussion. I shall therefore note but few points which seem to me to have an indicative value in connection with the question under consideration.

The most important fact concerning the Pacific coast which bears upon our problem is that the continental shelf, which is such a conspicuous feature along the Atlantic coast of Europe and North America, appears not to exist on that side of the continent. An examination of the marine soundings shown on the charts makes it probable that there is no such mass of recent sediments off the shore as exist in the submerged plain of the Atlantic coast or the emerged portion of it lying in the southern states of this Union.

The absence of a characteristic marine shelf may be accounted for in either of three ways: By the relatively small amount of land detritus borne into the sea at this coast; by a recent subsidence of the shoreline to such an extent that the shelf has been lowered to such a depth that the rare offshore soundings do not reveal it, or by the introduction of the shelf through elevation into the body of the land where its characteristic form has been lost through the recent mountain-building which has affected this part of the shore.

Although the Coast range is of late Tertiary origin, it does not seem likely that the rocks which are folded in it are of sufficient horizontal extent to explain the lack of a submarine shelf of the ample dimensions required by the large amount of erosion which the agents of sea and land have accomplished on the Pacific slope. Large as has been the amount of this wear, it is, however, less than that which has taken place upon the Atlantic versant of the continent, which has evidently been much longer exposed to degradation and probably also has been on

the average the seat of a greater rainfall than that of the western shore of the continent.

It seems to me that the facts do not permit us to assign any value to the absence in this part of the world of the submarine accumulations which are so marked a feature along the shoreline of the North Atlantic ocean.

Turning to the matter of flooded valleys, we find the first distinct indication of their presence at the Golden Gate. At this point there appears to have been a considerable river which has been extensively invaded by the sea.

From San Francisoo bay northward all the larger stream valleys as far as Alaska show more or less flooding. The waters of Puget sound appear to be those of a river-system which have been deeply borne down, though the details of the topography may have been considerably affected by ice-action.

In the peninsular part of the Alaskan district the flooding of the valleys does not seem to be so conspicuous as in the more southern portions of the Pacific shore. It may indeed be that this part of the continent has in recent times had a distinct excess of elevation as compared with the other marine shores.

### *RESULT OF THE OSCILLATIONS.*

In considering the ocean coastline of North America as a whole, we find that the facts go to show that in the region north of Mexico the changes in relative level of sea and land which have taken place in recent times have resulted in a tolerably uniform gain in the height of the sea. The fact must not, however, be overlooked that other evidence shows that this general downward tendency has been associated with many minor swayings which have occasionally carried the margin of the sea to much higher levels, and in one instance, and this in very recent times, has brought the continent on its eastern face to a relatively more elevated state than it has at present.

The various raised beaches, extending from North Carolina to high latitudes, indicate a brief subsidence in connection with the glacial event, while the submerged forests, extending from North Carolina at least as far north as the gulf of Saint Lawrence, containing plants of recent species, show very clearly a considerable downward movement since the Glacial epoch.

The impression left upon the mind of the observer is that, taking account only of the time which has elapsed since the beginning of that epoch, the eastern shore of North America from the Rio Grande to

Greenland has, though with many minor oscillations, been prevailingly lowered.

### *COASTS OF OTHER LANDS.*

*General Statement concerning Them.*—The question naturally arises: Does the evidence derived from other parts of the world show that this invasion of the land by the sea is likewise indicated by flooded valleys and other related facts. I shall therefore very briefly pass in review the coastlines of other lands, noting only the aspect of their river valleys and the evidence afforded by the distribution of animals and plants on islands near the shores. Thus far the facts concerning elevated and depressed sea-margins, except in northern Europe and the eastern United States, have not begun to be studied with the care which is necessary to make the results of much value to the inquirer pursuing the lines of research indicated in this paper.

*Caribbean District.*—Beginning with the Caribbean district, we find in the islands which constitute the eastern border of that area of inclosed water some interesting evidence, derived from the distribution of the living organic forms, that the Antillean archipelago has been subjected to a recent depression.

Some years ago Mr W. F. Ganong, instructor in the botanical department of Harvard University, was so kind as to prepare for me a table, showing the distribution of a large number of species through these islands, the forms being selected which were deemed of value for an inquiry as to the permanence of the division between these isles. From this list, as well as from the work of other inquirers, it appeared that there was no proof of long continued isolation of these bits of land, such as Wallace's researches have shown to have occurred in the islands of the East Indies. It is, indeed, difficult to account for the similarity of this life except on the supposition that the region has recently been one of connected land which was united with South America.

It may be well to note in this connection that the recent depression of Florida, the evidence of which has already been mentioned, may have been associated with the movement which lowered the lands of the Antillean district.

We may also observe that the salt deposits on the border of the gulf of Mexico in western Louisiana, which are probably of Tertiary age, indicate a period of very dry climate in that part of the world, a condition which would be brought about by the exclusion of the tropical current from the Caribbean district, such as a connected land barrier on the east would bring about.

*South America.*—On the eastern coast of South America such deltas as

occur along the shoreline extending from the Lesser Antilles southward are of the reëntrant type—that is, they have been formed in the upper parts of flooded valleys.

The flooding of the Amazon and the La Plata rivers constitutes the most extensive indentations of their kind in the world, while a number of minor streams afford similar though less important evidence of the same nature. I am aware that the absence of a normal delta in the valley of the Amazon has, to the satisfaction of some naturalists, been explained by the action of the incoming tidal wave moving in the form of an " eagre " or " bore " up the pathway of that stream. I am inclined to think that the importance of the work done by this irregular occasional wave has been much overestimated. Moreover, the form of valley, with its widely separated bluffs, as is the case with the lower portion of the Mississippi, clearly shows that the basin has recently been lowered to a considerable depth.

On the western shore of South America, as on the northern continent, the evidence concerning the present higher level of the sea is obscure as compared with that which has been obtained along the Atlantic coast.

In the Patagonian section the maps of the fiords appear to indicate the higher level of the shore at the time when the topography of the country was made; yet it should not be overlooked that these valleys now occupied by oceanic water may possibly be due to the cutting action of the ice.

The shoreline extending from Patagonia northward to the isthmus of Darien will have to be omitted from the discussion, as I have been unable to find any evidence indicating the flooding of valleys which is worth considering.

*Africa.*—The continent of Africa, so far as we may determine by the imperfect maps of its shoreline, affords less evidence of valley-flooding than any other of the great lands. It is also conspicuous for the lack of those islands near the main shore which often afford indications of recent subsidence.

So far as I have been able to find, data in the way of soundings to show the form and extent of the continental submarine shelf are not yet in shape for discussion. I am inclined to think that this feature exists there, but under the circumstances indicated have no opinion to offer as to its value. As a whole, the geographic and geologic indications which we have concerning Africa south of the Sahara lead us to suppose that the land has maintained its position with reference to the sea in a more permanent manner than has any other continent bordering on the Atlantic.

Within and north of the Sahara there appears to have been in Tertiary

times a considerable elevation, but the prevailing absence of river-valleys deprives us of the evidence which we obtain from the flooding of the same. The only valley which could afford a test, that of the Nile, has long been overfilled and has a salient delta, from which fact it is clearly evident that slight depressions of the surface would not produce an embayment.

*Australia.*—Australia, owing to the relatively small size of its rivers, due to its prevailing small rainfall, a feature which has probably been long continued, does not afford a favorable field for the discussion of the evidence of subsidence through the facts which are afforded by flooded valleys.

The rarity of coastal islands such as are normally produced by the invasions of the sea also serves to indicate that in modern geologic times this continent has not long stood above its present level. It appears, with Africa, to be of all the great lands among the least subjected to recent depressions.

*Asia.*—The southern coast of Asia has few reëntrants which appear to afford any evidence of valley-flooding. The deltas are of the salient type—that is, they have extended beyond the termini of the valleys in which they lie. While existing evidence is as yet too meager to warrant extended statements concerning the changes of level which have occurred along the shores, nevertheless the phenomenon cited, together with such other data as I can command appears to indicate that the land about the Indian ocean has not recently been higher than it is at present.

On the eastern coast of Asia the evidence points to a considerable, relatively modern subsidence, though the amount of it does not appear to have been anything like as great as that which has occurred along the shores of the North Atlantic ocean. The delta accumulations near the mouths of the valleys are considerable, but they do not have the complete salient form. Along the shores there are found numerous outlying islands, the existence of which can best be accounted for upon the theory of a recent submergence of a land topography. Moreover, the distribution of the organic life on these isolated areas points to the conclusion that they have in relatively modern periods been connected with the main shore.

*Europe.*—On the whole, the continent of Europe affords the clearest indications of extensive subsidence, in comparatively recent times, that are presented by any of the great land areas. The greater part of its river valleys are flooded at their mouths, only four or five of them exhibiting the phenomena of salient deltas, while the numerous islands have faunas and floras so like those of the mainland that there seems no escape

from the conclusion that their insulated character is of relatively recent date.

Along the north shore of Europe we find the same evidences of repeated oscillations, with an excess of recent subsidence, which are exhibited on the eastern shore of North America. In both instances submerged forests of recent species appear to indicate that the last considerable movement was one of downgoing.

*Northern Mediterranean Shore.*—Along the northern shore of the Mediterranean the topographic features seems to me to indicate an excess of subsidence. Although some of the islands along the coast may have their separation explained by differential warping or by marine erosion, there are many which can only be satisfactorily accounted for by the hypothesis of recent changes of level of the sea, and this for the reason that the valleys which part them from the mainland are narrow, river-like in their form, manifestly not due to marine erosion and not in a field where we can assume that to glacial wearing was due their segregation from the mainland.

*Islands of the Pacific Ocean.*—The evidence of marine changes of level afforded by the islands of the wide seas is not yet in shape for discussion. Such as it is, however, it appears to me to point to the conclusion, one of much importance, that the bottoms of the thallassal areas are now undergoing a process of warping which is sometimes downward and sometimes upward. Thus in the Pacific ocean some of the coral islands, by the great depth of water about their bases, lead us to believe that the region in which they lie is undergoing subsidence, while in other areas the contrary movement is indicated. In the time to come we may hope that a careful study of the evidence afforded by the islands which rise from the deep seas may enable us to chart in a general way, at least, some of the swayings which in recent times have affected in greater or less degree the bottoms of those areas.

## Conclusions.

The foregoing considerations, though giving but an outline sketch of the problems connected with the changes of level in sea and land, appear to me to afford an extension of our conceptions concerning the conditions which determine the positions of coastlines.

It seems to me to be evident that the position of a shoreline at any time and place is determined by an exceedingly complicated equation, in which there enter as factors not only the positive up-and-down movement of the area of the lithosphere on which the coast lies and the axial

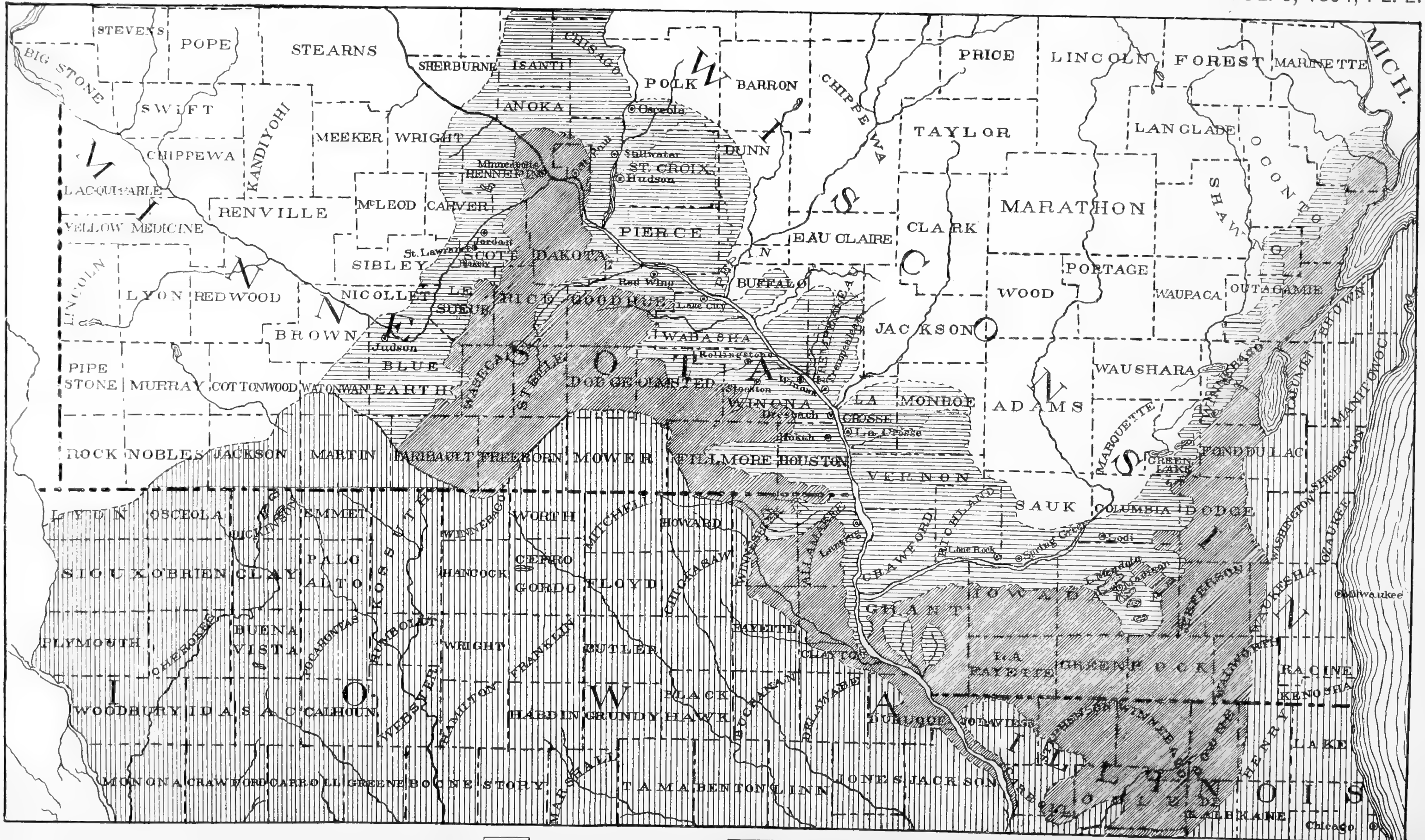
rotation or movement about a fulcrum line in relation to the shore, but also the form of the bottom of the deeper seas, the water-displacing value of other lands in their several movements of up-and-down going, the attraction of ice-caps, which rapidly vary in importance, that of mountains and other high-lying lands, which varies in a less rapid way, as well as other influences which have not been taken into account. It may be noted in passing that no reckoning has been made as to the progressive effect arising from the importation of sediments into the sea. The phenomena which are associated with this action are too complicated for discussion in this paper, where limitations as to length must be considered. It seems well, however, to advert to them.

So far we have not succeeded in obtaining data which will enable us to determine, even in an approximative way, the amount of detritus annually contributed to the bottom of the sea and there built into clastic rocks; yet we perceive that, in addition to the contribution from the lands borne in by the atmospheric agents and the waves and tides, there is probably a yet vaster amount contributed to the floor of the deep by volcanic ejections. As there is probably not more than about 10 per cent of the detrital accumulations which is occupied by the fluid, the effect of the deposition, except so far as it is compensated by the movements of the sea-bottom and the land masses, is to lift the plane of the oceanic waters in what may be termed a geologically rapid manner. This will be seen by a consideration of the following facts: The average downwearing of the land—that is, the rate of exportation of its materials to the sea-floor—is probably at least as rapid, taking into account both atmospheric and seashore actions, as 1 foot in 3,000 yards. The inquiries of various naturalists concerning the Javanese volcanoes appear to indicate that 100 cubic miles or more of detrital matter has been poured forth from these vents during the last hundred years, practically all of which has found its way to the sea-floor. The total amount of this contribution of sediments to the oceans from this small but very active group of volcanoes during the time mentioned probably exceeds the supply afforded by all the rivers of North and South America.

It thus appears to me evident that the water-displacing value of the marine sediments accumulated in the course of a million of years might, if other sources of change were excluded, suffice to affect the general sea-level to the amount of some score or perhaps hundreds of feet. Owing, however, to the other sources of instability of the land, this influence is perhaps of small value in the equation which determines the position of a shoreline.

Although I do not regard the facts above noted, which appear to show the prevailing low position of the coastlines of the world, as of decisive

value, they seem to me to raise the presumption that along a large part of continental coasts the average movement in relatively modern times has been of a nature to bring the coasts inwardly toward the centers of the continents. This may possibly be due to movements of the land-masses themselves, but it appears to me more likely that we should recur to the hypothesis of Strabo, briefly set forth in the opening paragraph of this paper, and account for them, at least in part, by alterations in the depth of the ocean floors.




*Pre Magnesian and Unknown* *Magnesian Series* *Ordovician* *Post Ordovician*

MAP SHOWING DISTRIBUTION OF THE MAGNESIAN SERIES IN THE NORTHWESTERN STATES.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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# THE MAGNESIAN SERIES OF THE NORTHWESTERN STATES

BY C. W. HALL AND F. W. SARDESON

(*Read before the Society August 15, 1893*)

CONTENTS

## Geographic Position of the Series.

The Magnesian series, which it is proposed to discuss in this paper, consists of several alternating beds of dolomite, dolomitic shale and sandstone. The series lies between the so-called Potsdam sandstone below and the Saint Peter sandstone above. It occurs in widely distributed localities throughout southern Wisconsin, southeastern Minnesota and northeastern Iowa. Nowhere in the states named has either one of the delimiting formations been found absent, save in eastern Wisconsin, where, at a single locality, Chamberlin found an arch of the billowy lower Magnesian rising into actual contact with the Trenton limestone and thinning out the Saint Peter sandstone to zero.*

## Historic Résumé.

A résumé of earlier investigations of the extent and contents of the Magnesian series of Minnesota has already been given by the writers.† To that résumé these notes can be added:

In Wisconsin the geologists of the last geological survey very carefully explored the lower Magnesian beds as they occur in that state.‡ They, however, relegated the Mendota limestone (Saint Lawrence) and the Madison sandstone (Jordan sandstone) to the underlying Potsdam. The lithologic and structural characters of the series are very fully discussed

*Geology of Wisconsin, vol. ii, 1877, p. 272.

†Paleozoic Formations of Southeastern Minnesota: C. W. Hall and F. W. Sardeson, Bull. Geol. Soc. Am., vol. 3, pp. 331–368 and plates 10–12.

‡See the Geology of Wisconsin, vol. i, 1883, pp. 138–144; vol. ii, 1877, pp. 268–285, 547–555, 577-607, 671–675; vol. iii, 1880, pp. 397, 398; vol. iv, 1882, pp. 64–81, 123–129, 194–204, 248, 249, 511–518.

on the various pages cited. Paleontologic notes also found there state that "some seaweeds, a few mollusks, an occasional fragment of a trilobite and a few obscure forms make up the meager list of fossils" which could with certainty be referred to this, the Mendota, limestone.*

In Iowa the lower Magnesian limestone has been noted in the northeastern portion of the State. It is most conspicuous along the upper Iowa river and in the valleys of Paint creek and Yellow river.† The thickest beds were 250 feet; the variations in texture and color were reported as considerable; the chemical composition varied but little from that of a pure dolomite; its brecciated and concretionary character was noted as a principal feature, and no fossils were found in the formation within the limits of Iowa. Twelve years later, however, Dr C. A. White stated that a few traces of the stems of crinoids had been found near McGregor. They were so fragmentary and indistinct that no identification of them could be made; also some traces of possible fucoids were found.‡

Recently W J McGee has very pointedly discussed the nomenclature of this series for Iowa § and for the broader northwest. ||

In the past year Professor Calvin, state geologist of Iowa, has noted the discovery of a fauna which leaves little doubt of the exact equivalence of the lower Magnesian limestone of Iowa and the Calciferous series of northeastern New York.¶

During the last two seasons, having gone over the ground in Minnesota more thoroughly and critically and having extended their studies into the adjoining states of Wisconsin and Iowa, the authors desire to discuss certain phases of the Magnesian series which were barely touched upon in their former paper. Those phases are partly stratigraphic and paleontologic and partly lithologic and genetic.

## Members of the Series.

### *ORDER OF OCCURRENCE AND THICKNESS.*

The Magnesian series consists of five formations, namely, three dolomites and dolomitic shales and two silicious sandstones. Enumerated in ascending order, they are: 1, the Saint Lawrence dolomites and shales; 2, the Jordan sandstone; 3, the Oneota dolomite; 4, the New Richmond

* Ibid., vol. i, p. 141.

† Geology of Iowa, James Hall, state geologist, vol. i, 1858, part 1, p. 332.

‡ Geology of Iowa, Charles A. White, state geologist, vol. i, 1870, p. 174.

§ W J McGee: The Pleistocene History of Northeastern Iowa, Eleventh Ann. Rep. U. S. Geol. Survey, 1889–'90, pp. 187–577.

|| Bull. Geol. Soc. Am., vol. 3, 1892, p. 461.

¶ American Geologist, Minneapolis, vol. x, 1892, pp. 144–148.

sandstone; 5, the Shakopee dolomite. Of these five formations the first three are considerable in vertical extent, reaching a thickness of 100 to 200 feet. Next above them the New Richmond sandstone is inconsiderable in thickness, seldom appearing more than a few feet and nowhere more than 20 feet. Lastly, the Shakopee, paleontologically important, since it carries a unique and well defined fauna, seldom reaches a thickness of 50 feet.

The following table shows the position of the series, with the maximum thickness of each division as determined for the states under consideration:

| | | |
|---|---|---|
| | Ordovician (Lower Silurian).... | Saint Peter sandstone. |
| | | Faunal break. |
| Magnesian Series. | (?) | Shakopee dolomite, 65 feet. |
| | | Faunal break. |
| | Upper Cambrian........... | New Richmond sandstone, 20 feet. |
| | | Oneota dolomite, 175 feet. |
| | | Jordan sandstone, 200 feet. |
| | | Saint Lawrence dolomite and sandy shale, 213 feet. |
| | | Faunal break. |
| | Middle Cambrian.............. | Dresbach sandstone. |

### *LITHOLOGIC CHARACTERISTICS.*

The considerations for grouping the five formations named under one term, "the Magnesian series," are partly lithologic and partly paleontologic. The lithologic are apparent when we consider the dolomitic composition of formations one, three and five; their uniform color, texture and structure; the secondary nature of their crystalline habit; the presence of intercalated oölite in them all; the regular occurrence of brecciated phases in each; and, finally, the entire absence of any known physical character by which the geologist could distinguish the special traits of each at any of its outcrops throughout the entire field studied.

The sandstones, formations two and four, are equally identical with

each other and bear similar relations to the dolomites with which they are interbedded.

*PALEONTOLOGIC CHARACTERISTICS.*

The paleontologic characteristics may be summarized as follows:

In the Magnesian series there are two faunas not united by a single species common to both; neither is the lower of these faunas united to the preceding nor the upper to the succeeding fauna by any more of a bond. This observation is the result of a comparison of all the brachiopoda, gasteropoda and cephalopoda at hand. It is believed that the same result will come from a comparison of the species of trilobita when the obstruction in identifying and locating geologically the large number of described species in this class of fossils has been overcome. Between the *Obolella polita* horizon, which, according to Charles D. Walcott, belongs to the Middle Cambrian,* and the next or *Dicellocephalus minnesotensis* (Saint Lawrence) beds of the Upper Cambrian occurs a very marked faunal change. This latter—that is, the Saint Lawrence (Mendota) formation—contains besides *Dicellocephalus minnesotensis*, Owen, *Lingula aurora*, Hall; *L. mosia*, Hall; *L. winona*, Hall; *Orthis* (*Billingsella*) *pepina*, Hall. Of these last named species a variety of the first, viz., *Lingula stoneana*, Whitfield, is found in the Jordan sandstone, and a form not yet distinguished from *L. mosia*, Hall, has been found in the Oneota (Shakopee B) formation.

*Orthis pepina* is found in the Saint Lawrence at the typical locality, Saint Lawrence, Minnesota, and is common to the Saint Lawrence, Jordan and Oneota formations. Again, *Raphistoma minnesotensis*, Owen, and *Murchisonia*, n. sp., are found in the Jordan sandstone, and are also very common in the Oneota. Mollusca have not been found in the Saint Lawrence (Mendota), unless those from Barraboo, Wisconsin, described by R. P. Whitfield,† belong here. *Metoptoma barabuensis*, Whitfield, has been found in the Jordan sandstone at Osceola, Wisconsin.

In the New Richmond (Elevator B) sandstone there are no fossils known to the writers, but stratigraphically it seems to belong to the Oneota (Shakopee B). In the Shakopee (Shakopee A) several species of mollusca are widely distributed geographically, since they have been found at Burkharts Mills and Argyle, Wisconsin; Cannon Falls, Utica, Shakopee and other places in Minnesota. They are specifically distinct from the fauna of the Oneota below, and they do not at all coincide specifically with any of the score and more of species from the Saint Peter sandstone above.

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* Am. Jour. Sci., 3d series, vol. 44, 1892, p. 56.

† Geology of Wisconsin, vol. iv, 1882, pp. 194-199.

A correlation of the Shakopee (Shakopee A) with the upper Calciferous of New York and the Oneota (Shakopee B) with the lower Calciferous seems to encounter few objections, although there is no present intention to set forth a decided opinion.

Thus it will be seen that the Magnesian series as understood by the authors includes all of the Upper Cambrian in the northwest and a part of the Lower Silurian (Ordovician), provided the Shakopee (Shakopee A) be correlated with the upper Calciferous and both referred to the Lower Silurian.*

## The Saint Lawrence Dolomites and Shales.

### *LOCALITIES.*

In Minnesota many exposures occur between Redwing and Lake City; at Rollingstone creek; the railway cut above Stockton; at Winona, Dresbach, Hokah, Stillwater, section 28 Saint Lawrence township; Jordan, section 30 Blakely township, and at Judson.

In Iowa they are to be found at several quarries around Lansing.

In Wisconsin they occur at Spring Green, Lone Rock, Lodi, McBride's point lake Mendota, Hudson and vicinity, Trempealeau, La Crosse and Osceola.

At Saint Lawrence, Minnesota, is found the type exposure, the rock in view representing the lower half of the formation. The Mendota limestone at the type locality described by Irving † represents the upper portion of the same formation. Were a division advisable into two parts the names Saint Lawrence and Mendota would not be synonyms, but would stand for different beds in what is now considered a single formation.

### *SPECIAL FEATURES.*

At section 28 Saint Lawrence, Scott county, Minnesota, about one mile south of Saint Lawrence landing, on the Minnesota river, there is exposed in one of the quarries six feet of a buff colored dolomite. Irregular laminæ of green shaly material are scattered through the entire rock exposed. A few rods farther southwest and in another quarry one foot of this soft greenish and laminated dolomite rock is seen overlying harder strata of a more crystalline dolomite. This last carries numerous green specks of varying sizes, which are commonly called glauconite. For a thickness of four feet this rock is very evenly bedded and carries the casts of a few absorbed fossils, particularly *Orthis pepina*, Hall. Beneath this layer is still another, which is seen three feet and which reaches to

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*Compare Charles D. Walcott: Am. Jour. Sci., 3d ser., vol. xxxv, 1888, pp. 398, 399.

† Geology of Wisconsin, vol. ii, 1877, p. 534.

an unknown thickness, is irregularly stratified and consists of conglomeratic dolomite and quartz sand in its visible portion. It is considerably colored with the same green mineral noticed in the two overlying layers. A peculiar concretionary structure appears here which resembles somewhat the *Spirophyton cauda-galli* of the Devonian, but is probably not of organic origin.

We thus have, at the typical locality, 13 feet of dolomite exposed. From N. H. Winchell's original description * we learn that he considered the rock silicious and harder than the Shakopee, evenly bedded and specked with green.

At Jordan, Minnesota, we find immediately beneath the Jordan sandstone a layer of dolomite six feet thick, soft, considerably altered by the percolation of water, and almost rainbow-colored in places. It is conglomeratic at the top. Below lies another layer, fine and firm, which at four feet from its top passes beneath the water level of the creek. The lithologic characters of the layers are slightly different. For instance, there is more coloring, locally, in the upper stratum and the second one is finer textured and discloses no absorbed fossils, so far as explored.

On the northwest quarter, section 12, Judson township, Minnesota, the uppermost layers of the Saint Lawrence formation are seen. They show varying lithologic and structural phases, as do the outcrops around Jordan and Saint Lawrence, already noted. In section 2, Judson township, along a slope descending from the crest of a terrace, blocks of dolomite are scattered. From eight to twelve feet below these blocks is a small quarry of thinly laminated dolomite, fine sandstone and green shale. Among them is one stratum of a more massive dolomite. Passing from this quarry northwestward many layers are concealed, while a few are exposed. Among the exposed and weathered slabs along the road are some of a semicrystalline, crinoidal character. The most westerly exposure of the magnesian series in the northwestern states is at Judson post office. The rock at this place is the same bed that occurs at Saint Lawrence. In traversing the distance from section 12 to the post office one passes down 40 or 50 feet in vertical descent from the contact of the Saint Lawrence and Jordan sandstone.

### *THE REDWING SECTION.*

At Redwing, Minnesota, occurs one of the best localities thus far found in the northwest for the study of the Saint Lawrence formation. A bald,

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* Geol. and Nat. His. Survey of Minnesota, Second Ann. Rep., 1873, p. 152 *et seq.*

clean exposure is here seen for the full extent of these beds. For that reason a somewhat detailed enumeration is here given:

| | | | |
|---|---|---|---|
| | Coarse sand—base of Jordan. | | |
| Saint Lawrence—total exposed thickness, 88 feet. | Fine sand, with mingled dolomite | 15 | feet. |
| | Dolomite, with mingled green shale | 15 | " |
| | Hard crystalline dolomite, becoming somewhat blue toward the bottom | 18½ | " |
| | Firm dolomite, with silicious grades | 6 | " |
| | Buff colored dolomite, with white and yellow sand | 7 | " |
| | Fossiliferous sand, with glauconite nodules and green shales | 16 | " |
| | Dolomite, "green sand" and shale | 2½ | " |
| | Breccia, changing downward into green shale and sand | 8 | " |
| (?) | Covered bank | 15 | " |
| (?) | Level of the Mississippi river at low water. | | |

## *THE "MENDOTA LIMESTONE."*

In Wisconsin this division of the old lower Magnesian limestone received from Irving the name Mendota limestone. It was referred, with the underlying and overlying sandstone, to the Potsdam.* It has been observed at several localities. At McBride's point, Mendota lake, the type locality, it—

"has a thickness of from 30 to 35 feet, of which the lower 20 feet are of a heavily bedded, dark yellow and brown, jointed, conchoidal fracturing rock, which is stained in seams and patches by the red oxide of iron and leaves on solution three to ten per cent of an aluminous and non-arenaceous residue. This rock quite closely resembles the lower portions of the lower Magnesian proper, having sometimes the concretionary structure characterizing that formation. The upper part of the Mendota about Madison resembles the lower, except in being in thin rough-surfaced layers and in carrying a somewhat larger percentage of silicious matter." †

In comparing further two typical samples, Irving points out the close earthy texture of the Mendota and the porous and highly crystalline character of the so-called Magnesian.

In Iowa the exposures of this formation are not important. At Lansing the uppermost 35 feet that lie exposed show a finely textured fossiliferous dolomite interlaminated with micaceous layers. Immediately below this is a green shaly glauconitic dolomite 15 feet in thickness. It

* Geology of Wisconsin, vol. ii, 1877, pp. 260; 535; 544.

† Ibid., p. 543.

is hard and of a buff color. The lowest bed seen is a soft dolomite in sight for about 4 feet. McGee says:

"The limestones are magnesian, always more or less sandy, and generally heavy bedded or massive; the shales are imperfectly fissile, commonly calcareous and sometimes richly fossiliferous, as at Lansing, where they are charged with fine specimens of *Dicellocephalus minnesotensis* and other characteristic Upper Cambrian forms." *

The Saint Lawrence is essentially a dolomite, yet at the top it shows an interlamination of dolomite and sandstone, which appears to be the transition from this formation to the overlying Jordan sandstone.

### *FAUNAL CHARACTERS.*

The faunal characters of the formation are not marked. It may be said, however, that fossils have been found in nearly every exposure examined in the three states under consideration. The representative species are:

*Dikellocephalus minnesotensis*, Owen.
*Lingula aurora*, Hall.
*Lingula mosia*, Hall.
*Orthis pepina*, Hall.
*Raphistioma minnesotensts*, Owen.

For collecting the most productive places are perhaps Osceola, Hudson, Trempealeau and Lone Rock, Wisconsin; Marine Mills, Redwing, Hokah, Minnesota, and Lansing, Iowa.

## The Jordan Sandstone.

### *LOCALITIES.*

In Minnesota, Jordan, Ottawa, Mankato, Minneopa falls, Rapidan, section 12 Judson, Stillwater, Hastings and the whole length of the Mississippi river in the state, Bear creek, above Stockton on the Winona and Saint Peter railway, and Rollingstone.

In Iowa, Lansing and McGregor.

In Wisconsin, Lone Rock, lake Mendota and Madison, Osceola, and Hudson.

### *SPECIAL FEATURES.*

At Jordan, Minnesota, this sandstone has its typical outcrop. It occurs on Sand creek, about half a mile above the village. In the bed of the creek it seems somewhat calcareous. The color is reddish at the

* Eleventh Annual Report U. S. Geological Survey, 1889-'90, p. 333. It is to be noted that Mr McGee includes these beds in the Potsdam.

surface, while the quarried stone generally shows a white color. There are rusted interlaminations producing a streaked section of rusted and white layers.*

### *THE "MADISON SANDSTONE."*

The Madison beds in the country about Madison, Wisconsin, are 35 feet thick and consist usually of pure white, frequently loose, sand overlaid by brown and yellow firmer rock. The upper layers generally show a slight calcareous admixture which locally increases to 10 or 15 per cent of the rock. It then becomes a good building material and is not very sharply defined from the limestone above. Near the village of Middleton the bulk of the sandstone consists of a light yellow, friable, fine grained dolomitic sandstone, composed of rolled quartz grains embedded in a crystalline dolomitic matrix, the sand being 63.4 per cent of the rock.†

As a whole; this sandstone is coarse grained at the bottom, becoming finer grained toward the top of the formation. It seems everywhere to be characterized by a strong crossbedding, as instanced at Hastings, Minneopa falls, Rapidan, and particularly Osceola. At the last named place, at an exposure near the railway station, crossbedding can be seen reaching a thickness of from four to six feet. As a rule, this rock is a clean white sand, the coloration seeming always to be a local phenomenon. At Osceola in the fossiliferous beds the color is a reddish brown, which is due to an infiltration of fine oxide possibly from the surface, since the rock was laid bare by denudation of the overlying formations.

The thickness of the Jordan varies considerably, ranging between 35 and 90 feet. At the typical locality N. H. Winchell gives the total as 51 feet.‡ The writers, however, have at this same locality noted only 35 or 40 feet. At Osceola about the same thickness has been observed. At Rapidan, in the Minnesota river valley and Bear creek, near the Mississippi river, the thickness varies from 70 feet to 90 feet; at Lansing, 70 feet can be measured, with perhaps an additional 15 feet of sandstone belonging to the Jordan. Thus the formation thickens toward the south.

### *FAUNAL CHARACTERS.*

Touching the paleontology of this sandstone formation it must be said that in most localities fossils cannot be found. They are most numerous at Osceola, Wisconsin, of all the exposures visited by the writers. Large numbers of gasteropods and trilobites are found here. At Rapidan, Minnesota, are some gasteropods. Scolithus tubes will reward search in

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* Geol. and Nat. Hist. Surv. Minn., Ann. Rep. 1873, N. H. Winchell and S. F. Peckham, p. 149.

† R. D. Irving: Geology of Wisconsin, vol. ii, 1877, pp. 535, 542, and other places.

‡ Loc. cit., p. 149.

almost every locality. They are particularly abundant in the layers well toward the top of the formation.

The following forms will serve to illustrate the Jordan fauna:

*Bellerophon antiquatus*, Whitfield.
*Pleurotomaria* (*Holopea*) *sweeti*, Whitfield.
*Ophileta*, sp.?
*Murchisonia*, sp.?
*Lingula stoneana*, Whitfield.
*Orthis pepina*, Hall.
*Raphistoma minnesotensis*, Owen,

with a number of undetermined trilobites.

## THE ONEOTA DOLOMITE.

### *LOCALITIES.*

In Minnesota: Mankato, Kasota, Saint Peter, Ottawa, Stillwater, Point Douglas, Hastings, Red Wing, Rollingstone, Bear creek, above Stockton; Winona, Dresbach and Lanesboro.

In Iowa: Lansing and McGregor.

In Wisconsin: Osceola, Hudson, Burkharts Mills, Prescott, Maiden Rock, Prairie du Chien, Woodman, Middleton station, Madison, Lodi, Blanchardville, and many other places.

### *THE NAME "ONEOTA LIMESTONE."*

The name "Oneota limestone" is given by W J McGee* to include practically the lower Magnesian limestone of D. D. Owen.† It is not clear that Owen was aware of the existence of the upper division (Shakopee), which McGee refers ‡ to the Saint Peter sandstone, since the lower division is the conspicuous one and the upper very obscure in all natural exposures.

Professor Irving's "main body of the limestone" applies only to the more prominent formation; also Winchell's name "Shakopee limestone," it would seem, was intended to cover what had been included in Owen's lower Magnesian limestone, but as a matter of fact was applied not only to the Shakopee, which alone is seen at Shakopee, Minnesota, a formation which Owen probably never saw, but also to the lower greater formation exposed at Merriam Junction, Ottawa, Mankato, and other places in the Minnesota river valley.

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* W J McGee: Pleistocene History of Northeastern Iowa, Eleventh Ann. Rep., U. S. Geol. Survey, Washington, 1891, p. 331.

† Report of a Geol. Survey of Wisconsin, Iowa, and Minnesota, Philadelphia, 1852, p. 58.

‡ Pleistocene History of Northeastern Iowa, table on page 332.

In later instances Winchell used the term Shakopee for the Shakopee horizon* only, and by error designated the lower portion and the intercalated sandstone as Saint Lawrence limestone and Jordan sandstone respectively.

Subsequent discoveries by Warren Upham in the Minnesota river valley,† which harmonized with earlier observations by L. C. Wooster in Wisconsin,‡ led to the recognition by the writers in 1892 of the Shakopee A dolomite (= Shakopee); Elevator B sandstone (= New Richmond), and Shakopee B dolomite (= Oneota); Lower Magnesian limestone, Owen; main body of limestone, Irving; Shakopee B limestone, Upham, and at least six different terms or designations used at different times by N. H. Winchell § as terms take precedence over McGee's Oneota; but inasmuch as it seems impracticable to free the older terms from a great burden of error and complication the new and clearly defined term Oneota of McGee is preferred. Further, the term Oneota is the only one of all hitherto used which is referred to a typical locality.

### *PHYSICAL CHARACTERS.*

The Oneota is typically a porous dolomite in heavy, uniform layers. Generally in the upper part the formation has been penetrated by numerous water channels, leaving cavities and fissures which are now lined with finely crystalline quartz or filled with quartz concretions. The original stratification is doubtless wholly obliterated and the pseudostratification, which now occurs and is in many places sharply distinct is much disturbed. This is generally true for the upper portion of the formation and more rarely for the formation as a whole, as at Point Douglas, Minnesota. At this locality layers several feet in thickness are squeezed out in the distance of a few paces. Accompanying this disturbed and compressed condition of the dolomite is a compact texture, which in turn is frequently associated with a fractured, brecciated or pseudoconglomeratic structure, or even with foreign material, as sand grains imbedded in the cracks and seams. The disturbed condition of the pseudostratification leads to a thinning out of the beds within small areas. Sometimes the whole formation seems to be undulated, as at Ottawa, Minnesota, while elsewhere the base of the formation is horizontal and the irregularity of lamination and undulation increase toward the top. The upper surface of the Oneota is perhaps always uneven from

* Bull. Minn. Acad. Nat. Sciences, 1875, vol. i, p. 156; Geol. and Nat. Hist. Survey Minn., Final Rep., vol. i, 1884, p. 219.

† See Hall and Sardeson, Paleozoic Formations of Southeastern Minnesota, Bull. Geol. Soc. America, vol. 3, 1892, p. 341.

‡ Geology of Wisconsin, 1882, vol. iv, p. 106; loc. cit., p. 342.

§ Hall and Sardeson, Bull. Minn. Acad. Nat. Sci., vol. iv, No. 1.

this cause; its thickness varies from 50 feet, as at Red Wing, to 250 feet elsewhere.

Sometimes there are pockets of an argillaceous shale, like the remnants of rock beds, near the top of the formation, as at Blanchardville, Wisconsin, and Clay Bank, Minnesota, and perhaps always at its top an interstratification and intermixture of quartz-sand and oölitic dolomite prevails. Such phenomena are clearly seen at Mankato and Lanesboro, Minnesota, and many other places. The intervening dolomite of these upper beds contains many fossils which disclose the Oneota features.

The base of the Oneota or the top of the Jordan sandstone is always a mixture of quartz, sand and dolomite or an alternation of such layers for several feet. Rarely has the removal of a portion of the carbonate material by percolating waters given a sharper demarkation between the two formations.

### *FAUNAL CHARACTERS.*

The fauna of the Oneota, so far as known, includes but few species, nor are these abundant. Described species are:

*Raphistoma* (*Euomphalus*) *minnesotensis*, Owen.
*Halopea obesa*, Whitfield.
*Orthis pepina*, Hall.

To which may be added:

*Asaphus*, sp.?
*Lingula*, sp.?
*Murchisonia*, sp.?
*Ophileta*, sp.?
*Struparollus*, sp.?
*Endoceras*, sp.?
*Cyrtoceras*, sp.?
*Ascoceras*, sp.?
*Piloceras*, sp.?

The richest localities for fossils are Osceola, Hudson and Blanchardville, Wisconsin; Mankato, Merriam Junction, Redwing, Lewiston and Stillwater, Minnesota.

## The New Richmond Sandstone.

### *LOCALITIES.*

In Minnesota: Mankato, Kasota, Cannon Falls, Clay Bank, Isinours and Caledonia.

In Wisconsin: New Richmond, Burkharts Mills and Argyle.

In Iowa no locality has yet been seen by the writers.

This bed was detected in the banks of Willow river, in eastern Wisconsin, in 1876–'77, by Assistant Geologist L. C. Wooster.* No descrip-

* Geology of Wisconsin, vol. iv, 1882, p. 106.

tion of this bed was given, and not even a locality where its typical development could be seen was named. Merely the existence of such an interpolated sandstone between the upper layers, "the Willow river bed," and the more massive portion of the Magnesian limestone was announced.

*PHYSICAL CHARACTERS.*

In 1883 Warren Upham, in discussing the "Shakopee epoch," observed that the—

> "formation incloses a more or less persistent layer of sandstone 20 feet thick in the deep well at Elevator B, in Saint Paul, which is probably the Jordan sandstone of Houston and Fillmore counties, except perhaps at Lanesboro, and of Olmsted county, except perhaps at Quincy." *

This is usually a pure white quartz-sand. It is loosely cemented, indistinctly stratified and indistinctly separated from the underlying Oneota, a fact which points strongly to the lack of any line of separation from that formation save the lithologic one. No fossils whatever have been found to aid in its closer identification and reference. At Saint Paul, Upham found this sandstone 20 feet in thickness; at Lewiston it is 12 feet; at Mankato, 6 feet, and is interlaminated with a green unctuous shale.

So far as the observations of the writers go, the New Richmond sandstone is entirely devoid of fossils. Its delimitation from the Oneota is therefore wholly lithologic. Inasmuch as in other cases—for instance, between the Jordan and Oneota—the transition is through successively alternating strata, the New Richmond may prove to be an arenaceous cap to the Oneota beds when further localities have been explored or fossils have been discovered.

## The Shakopee Dolomite.

*LOCALITIES.*

In Minnesota: Shakopee, Cannon Falls, Northfield, Clay Bank, and Utica.

In Wisconsin: River Falls; on the Willow river, especially at Burkharts Mills; Prairie du Chien, Argyle, and Pickett station.

In Iowa: McGregor and Giard.

*PHYSICAL CHARACTERS.*

The Shakopee formation is mainly a dolomite of various texture—fine, soft, compact, crystalline, subcrystalline, rough, porous, etcetera. In

*See also Paleozoic Formations of Southeastern Minnesota, Hall and Sardeson: Bull. Geol. Soc Am., vol. 3, 1892, p. 341.

some of the layers that obtain there is a predominance of quartz sand, while others are fine shaly layers, often broken into isolated pockets. The base of the Shakopee has generally an oölitic layer—as, for example, at Mankato, Minnesota—sometimes mixed with quartz sand, as at New Richmond, Wisconsin; the main body of the formation here and there contains pockets of sand, oölite, or clay, while the upper strata are largely composed of sand, between which are dolomites, with Shakopee fossils, wherever fossils occur. This lithologic condition gives the appearance of stratigraphic unity between the Shakopee and the overlying Saint Peter, which McGee has noticed in Iowa.* In Wisconsin, on the other hand, shales in places replace the sandy layers of the top of the Shakopee and the lithologic delimitation becomes as sharp as the paleontologic.

The folding in the top of the Oneota is carried upward into the Shakopee and even becomes increased in this formation, as can be clearly seen in some localities, while elsewhere the yielding layers of the New Richmond sandstone seem to afford a line of readjustment. Extreme folds usually abound in cryptozoönic concretions. Sometimes even these concretions are found broken, forming a breccia or pseudoconglomerate with a sandstone, but more usually dolomite, matrix embedded in the mass of the Shakopee.

When fossils are found in the Shakopee they are very numerous. They are also very fragmentary, owing to the universal dislocation which the strata of this formation have undergone.

#### *FAUNAL CHARACTERS.*

The fauna of the Shakopee is very well defined. Its forms assure the writers in the statement made in the table on page 170, locating the series. Present identifications place them in the genera *Murchisonia*, *Raphistoma*, and *Subulites*, which are very similar to species described by Billings from the upper Calciferous. A few specimens of *Endoceras* and *Litnites* also occur.

The best localities for gathering the above are Shakopee, Cannon Falls, and several places in Winona county, Minnesota, and at Argyle and near Hudson, in Wisconsin.

### The Lithology of the Series.

#### *THE SANDSTONES.*

The lithologic characters of the Upper Cambrian sandstones may be succinctly stated. Their chemistry promises so few results new to geolo-

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*Pleistocene History of Northeastern Iowa, p. 331, already cited.

gists that an investigation along this line was not entered upon. In their typical development these sandstones are masses of clear rounded grains of quartz unmixed with any other material. From this typical condition they merge into clearly defined shales which are both aluminous and calcareous in composition. These shales in turn pass into the carbonates of typical constitution.

In the typical sandstones the grains are almost wholly quartz. Where the color is white the mass is nearly pure silica. Each individual grain is worn smooth and well rounded, so that under magnification it is well polished. There is considerable variation in size; in places quite wide extremes are offered in coarseness. At Redwing and Mankato, Minnesota, even a conglomeratic texture is reached. In nearly all localities where these sandstones are strongly developed the lower beds are the coarser. Nowhere, however, has there been seen what may be considered a basal conglomerate such as underlies the Potsdam at every point in Minnesota where the base of that formation is exposed.* It is possible there might have been laid down such a conglomerate whose immediate sources would lie in limestones, shales and friable sandstones of every varying phase. The ready solubility of the limestones, together with the easy degradation of imperfectly lithified shales, make it quite improbable that in this case there was the usual permanent conglomeratic floor on which subsequent layers were deposited.† The Jordan sandstone has many layers of very coarse sand intermingled with those of very ordinary texture.

A cementing of the sand grains is locally seen. At Utica and Jordan, in Minnesota, the Jordan sandstone has sufficient firmness to be used in bridge-building and coarse foundation work.

The cement at these places seems to be a carbonate infiltrated from the overlying rock. It fills the interstices of hundreds of cubic yards; it indurates vertical or horizontal sheets of the sand, or it forms concretions of various, even fantastical, shapes. Where the sandstone thus consolidated is broken it displays in the broad reflecting surfaces, sometimes inches across, the effect of crystallizing forces. The calcium carbonate is deposited among the quartz grains in the crystallographic form of calcite over large areas and exhibits the characteristic cleavage of this mineral.‡ Fine illustrations of such cementation occur below Stockton and at Lanesboro, Minnesota, and elsewhere in both Minnesota and Wisconsin. Again, as at Ottawa, in the upper layers of the Jordan the grains are cemented with silica. A hand specimen taken within a

*Paleozoic Formations of Southeastern Minnesota, Hall and Sardeson: Bull. Geol. Soc. Am., vol. 3, 1892, p. 336.

†R. D. Irving: Seventh Ann. Rep. U. S. Geol. Survey, 1885-'86, p. 397.

‡Paleozoic Formations of Southeastern Minnesota, already cited, p. 345.

few feet of the top shows the rounded quartz grains built out into clearly defined crystals by the deposition in crystallographic continuity of pure transparent silica. Irving first studied this phenomenon in the sandstones of the northwestern states,* as well as that of quartzite-building, which is beautifully exemplified in this same sandstone layer at Osceola, Wisconsin, near the station buildings of the Minneapolis, Saint Paul and Sault Ste. Marie railway. Thin layers are scattered through the rock, in which the grains have not only been enlarged, but they have attached themselves together into a very firm nongranular quartzite. As the nearly vertical walls of sandstone are eroded, these quartzite layers stand out as shelves of rock, resisting atmospheric effects and disappearing only when gravity breaks off pieces whose attachments are weakened through frost and fractures. The quartz grains of these layers are cemented together by the deposition of silica in crystallographic continuity, and the extreme cleanness of the surfaces of the original grains makes it difficult to tell in most cases where the contact of the old and new material lies.

### *THE SHALES.*

The Upper Cambrian shales are but little known in the northwestern states. In Wisconsin seams of shale are intercalated, particularly in the basal portion of the series † (Saint Lawrence), with a varying amount of aluminous impurity present throughout the rock. In Iowa shales seem to be wanting, the rock being firm and presenting bold and picturesque bluffs along the valleys. In Minnesota the borings of artesian and deep wells disclose a frequent shaly condition of the Saint Lawrence. Field explorations confirm the view that the Shakopee must once have been an extensive series of shales and limestones. The Oneota was a tolerably pure limestone and the Saint Lawrence was partly limestone and partly shale, and of great thickness. Quarries, as at Shakopee and Merriam Junction, Minnesota, carry pockets of a clayey shale, which appears originally to have been quite regular and continuous strata, but now are squeezed out and reduced in bulk, or by a process of replacement have passed into an impure dolomite. The brecciated condition frequently seen may have a similar origin. The angular fragments of the brecciated layers are from a finely textured rock and they show on their surfaces as well as within their mass the marks of having been dissolved to a considerable extent while the transformation from their original condition to their present one was taking place.

Nodules are characteristic of the topmost layers of both the Shakopee

* On Secondary Enlargements of Mineral Fragments in Certain Rocks, Irving and Van Hise: Bulletin no. 8, U. S. Geol. Survey, 1884, p. 40, pl. ii.

† Chamberlin: Geology of Wisconsin, vol. i, 1883, p. 140.

and Oneota formations. Nodule-building in all its stages can be followed in the examination of these layers.

### *THE DOLOMITES.*

*Lithologic Characters.*—Both lithologically and genetically these are the most important Paleozoic rocks in the northwestern states. It is a question of what they have been as well as what they are. Their lithologic characters were briefly discussed before this Society one year and a half ago,* and but little of that discussion need be repeated here. All sedimentation bands are obliterated save in rarely protected localities. A pseudo-lamination is sometimes seen, produced generally by the alternation of finely textured, compact bands with coarser and porous ones. These porous bands at times become highly vesicular and by the disappearance of the walls of the vesicles a truly cavernous condition may obtain as at Nininger and Hastings, Minnesota. When the spaces thus formed become filled with white calcite a series of alternating dolomitic and calcitic laminæ is developed, thus producing a sort of cryptozoönic structure. This structure at Lanesboro can be traced along the face of the bluff for hundreds of feet horizontally and tens of feet vertically. The calcite bands are usually less than half an inch broad. The narrower ones show an interesting embedding of dolomite crystals in the coarsely crystalline calcite. The mass of the rock is made up of dolomite crystals and grains. The rhombohedral form is persistent in them. This same tendency to develop rhombohedral crystals has been noted elsewhere. Fischer-Benzon,† a quarter of a century ago, described the clearly rhombohedral attitude of the dolomitic constituent in a series of Silurian rocks examined by him. He also called attention to the various impurities characterizing those rocks. Near the Stockton quarries the degeneration of the porous condition is so complete that shovelfuls of loose sand consisting of dolomite rhombohedra can be taken up. This corresponds to that very complete stage of physical alteration seen in granitic districts where masses of the rock are subjected to aërial degradation until only fragments of feldspar and quartz lie mingled in a bed of loose, unrolled débris.

The strongest distinction between the coarser and the finer and firmer portions of these dolomites lies in the size of the grains and the absence of well developed rhombohedra in the finely crystalline portions. This obliteration of rhombohedra is effected through the contact of neighboring individuals. Impurities abound, yet they can be differentiated by chemical analysis with more precision than by microscopic identification.

* This Bulletin, vol. 3, pp. 346–348.

† Neues Jahrbuch für Mineralogie, u. s. w., 1869, p. 853.

*Silicious Segregations.*—An oölitic structure is locally present, and the oölite is both silicious and dolomitic. The former is likely to be found in those beds which carry the silicious concretions and silicified fossils, mentioned on page 347 of the former paper just referred to. These concretions present many interesting problems. They consist of silica in two different phases: (1) Quartz attached to original grains in crystallographic continuity and (2) microcrystalline, that is, chalcedonic quartz. With each of these phases are many original and well rounded grains of quartz which, with the chalcedonic as well as the crystallized phase, serve as nuclear grains for the segregation of considerable silica.

The second type was used to a considerable extent by the former dwellers along the river valleys and lake shores in making arrow-heads, spear-points, etcetera, because the segregations were frequently large enough to enable the workmen to chip down from fragments until a well dressed tool or weapon was perfected.

Segregations of silicious sand grains are frequently seen in vertical arrangement, as if canals had been dissolved in the dolomite and these grains from subsequent sediments had fallen down to occupy the cavities thus formed in the rock. Such specimens were particularly fine about Merriam Junction and Isinours, Minnesota.

*Glauconite Grains.*—In addition to the miscellaneous impurities just mentioned, including the several phases of free silica, there occurs quite generally in certain positions a green mineral which is known as glauconite. Some years ago Professor Peckham analyzed the mineral.* The mean of four analyses is as follows:

| | | |
|---|---|---|
| $SiO_2$ | 48.18 | per cent. |
| $FeO$ | 27.08 | " |
| $Al_2O_3$ | 6.97 | " |
| $K_2O$ | 7.40 | " |
| $Na_2O$ | 1.25 | " |
| $H_2O$ | 8.75 | " |
| Total | 99.63 | " |

This result agrees closely with the composition of the New Jersey glauconites † of Lower Tertiary and Cretaceous age and that of recent deposition as determined by v. Gümbel ‡ in his examination of the dredgings brought up by the *Gazelle.* Still, taking the results in reversed order from that cited above, we note in following down from recent glauconite

* S. F. Peckham: Report on Chemistry, Ann. Rep. Geol. and Nat. Hist. Survey, Minnesota, 1876, p. 61; 1879, p. 152.

† Dana's System of Mineralogy, fifth edition, 1882, pp. 462, 463.

‡ Neues Jahrbuch für Mineralogie, u. s. w., Ref. 1889, i, p. 20.

to the Cambrian a steadily increasing percentage of alumina. The mineral usually occurs in grains more or less regular in outline, many of them being elliptical or spherical and others decidedly subangular. In the Saint Lawrence there are places where the glauconite is distributed in the interstices of the rhombohedral grains of dolomite, showing almost no tendency toward segregation into the compacted granular condition, as is the case with the silica. The color is a bright green, sometimes browned with ferric oxide; in either case they form a sharp contrast to the dirty white, the usual color of the normal dolomite, in which they are imbedded. These glauconite grains are extremely finely textured, so fine indeed that it requires high magnification to analyze them. They are slightly dichroic and respond in a very weak degree to tests under crossed nicols. No relation could be traced between the form of the grains and the form of possible forameniferal shells or other organic remains; neither could any indication of detrital origin be seen. It may be added that it is difficult to understand, with the vast changes in bulk, chemical composition and crystalline condition which these rocks have certainly undergone, how any organic shells or even casts could have withstood the varied vicissitudes to which they have been subjected. How the green color could be retained through all the changes, chemical and physical, which the rock formation has undergone is equally difficult to understand. The origin, therefore, of these glauconite grains is looked for not in the conclusions of v. Gümbel,* Murray and Renard † or Clark,‡ who closely follows Murray and Renard, but rather in the chemical conditions of the mingled mineral matters of the including rocks, a view which Dr. T. Sterry Hunt repeatedly set forth.§

*Dolomitic Conglomerate.*—In several connections the writers have already called attention to the conglomeratic condition found in the top of the dolomites. Broadly stated, it may be said that the summit of each of the three dolomitic formations is to a considerable extent conglomeratic. This texture is not always so clearly conspicuous as in the Shakopee at Lanesboro, Minnesota, and at other places in Minnesota and Wisconsin. There is great diversity in the size of the pebbles in these conglomeratic layers, but a remarkable uniformity of shape exists. They are nearly always lenticular. In texture they are finer than the dolomite of their matrix or of the lower layers of the formation. The conglomeratic phase may be retained, since the finer and denser texture of these pieces resists

* Ibid., p. 20,

† Challenger Expedition Reports, volume on Deep-sea Deposits, p. 387.

‡ Ann. Rep. Geol. Survey of New Jersey, 1893, p. 238.

§ Chem. and Geol. Essays, 1878, p. 303; Mineral Physiology and Physiography, 1891, pp. 196, 309; Systematic Mineralogy, 1892, p. 257.

more effectually the percolation of underground waters and their solvent power than the more coarsely crystalline portions associated with them.

## The Genesis of the Series.

### *THE SANDSTONES.*

Silicious sandstones are being deposited at the present time as marine accumulations and river debris; yet nowhere, so far as the writers can read, are they so white and mono-component as are the lower Paleozoic sandstones of the upper Mississippi valley. Throughout most of the beds there is only one constituent, and that is clear quartz. As has already been shown, there are impurities, the chief two being an extremely fine kaolinic material and a ferric oxide, which colors the beds locally. Nowhere have been found those other minerals, rutile, zircon, etcetera, so frequent* in common sands and sandstones.

To assume that the conditions of sandstone-building in the early Paleozoic were fundamentally different from those of today offends the judgment and soberer second thought. The sources of supply for the vast quantities of quartz which these sandstone beds display was doubtless in the extensive mountain ranges which then must have stood to the north and west, a few of whose ridges still stand exposed as isolated stumps of schistose, gneissic and granitic masses in the outcrops of the region between lake Superior and the Black hills, or are reached in other localities by the tool of the well-borer.

The extent of those ranges cannot here be discussed, neither can the mode of deposition of the sediments derived from their degradation. The latter, however, may be assumed to have been laid down along a vast shore-expanse, perhaps a Cambrian continental plateau in area, scarcely less than the plateau off eastern North America at the present time, since the deposits stretch from eastern Wisconsin through Minnesota, Iowa and Missouri. Further, the conditions of deposition must have been extremely uniform and quiet. Periods of deeper submergence are marked off in the continuous history by beds of dolomites—the remains of original limestone deposits.

The origin of the sandstones may confidently be referred to the erosion of crystalline rocks, consisting of granites, gneisses, schists, and quartzites, because of the uniformly pure silica which makes up the successive beds. The pebbles in any sandstone are characteristic of the series from which they are derived, so basic eruptives could have played no part in the production of these clean and almost wholly silicious beds.†

As they were originally formed, these sandstone beds were more or less

* A. Geikie: A Text-book of Geology, third edition, London, 1893, p. 129.

† Compare Irving and Van Hise: The Penokee Iron-bearing Series of Michigan and Wisconsin. Mon. xix, U. S. Geol. Survey, 1892, p. 462.

shaly at the bottom and top. It is further fair to assume that a formation like the Jordan, still from 75 feet to 200 feet in thickness, originally must have been a succession of sands and shaly sandstones. A typical modern section of such a succession may be seen in the upper portion of the marine division of the New Jersey Cretaceous,* since a marine fauna has been found in the Jordan sandstone at Osceola, Wisconsin, and Rapidan, Minnesota.† It is evident that calcareous beds also were laid down with the sandstones and shales, since the faunas already discovered give strong assumption of still others, now entirely obliterated through the chemical changes of which the present condition of the rocks bears such strong indications.

With the above considerations in mind, it seems highly probable that the present condition of the sandstones has been reached through prolonged physical and chemical action, the physical action being chiefly effected through flowing waters and transported solids, the chemical through the dissolving and redistribution of mineral compounds, including the removal of those more soluble portions which are naturally deposited in the building of every sandstone bed.

### *THE SHALES.*

Touching the origin of the shales, but little need be said in addition to what was stated concerning the lithologic characters of the sandstones in the preceding paragraphs. The shales are the most natural deposits between sands and calcareous organic remains; indeed, it is hard to understand how an alternation of sandstones and limestones could occur without the interposition of a shale. As the carbonates in subsequent alterations become changed by reduction and dolomitization, so the shales, to some extent carbonates in chemical composition, should become reduced in thickness and altered chemically to more alumino-silicious beds than were the original deposits. This view of the origin of shales is far from new; indeed, Grandjean, in 1844,‡ suggested this origin by exfiltration of the carbonates. He called attention particularly to the lack of schistosity in those layers which contained a large percentage of calcium carbonate and in which the fossils were in a good state of preservation. To show that the same physical conditions prevailed throughout the entire period of formation-building, Grandjean points out the fact that the same fossils occur, however different the present conditions of the rocks may be. This fact is a significant one when carried over into the study of the various members of the Magnesian

* C. A. White: Correlation Papers, Bull. no. 82, U. S. Geol. Survey.

† See ante, p. 177.

‡ Die Dolomite und Braünstein: Lagerstätten in untern Lahn-Thale, Neues Jahrbúch für Mineralogie, u. s. w., 1844, p. 551.

series, and particularly the Saint Lawrence, with its varied lithologic characters and wide distribution.

*THE DOLOMITES.*

*Historic Outline.*—Long before chemical and physical facts were known or geology had become a science, dolomites received considerable attention. In 1779 Arduino had traversed the carbonates around Lavina and reached the conviction that this deposit of carbonate of lime and magnesia was formed from calcium carbonate through the operation of igneous agencies originating in the depths of the earth.*

In 1792 de Saussure † recognized dolomite as a distinct rock species instead of a peculiar modification of limestone through metamorphism and gave to the species the name dolomite, in honor of his contemporary, Dolomieu, who had already noted some of its most prominent characters. Heim,‡ in his geologic description of the mountains of Thuringia, apparently independently reached nearly the same conclusion touching the alteration of the limestones as had Arduino a generation before him.

Leopold von Büch, in a series of interesting letters § written mostly in 1822, described many of the phenomena of bedding and relationships in the dolomites of Frankenland, various portions of Tyrol, and the neighborhood of the Eifel volcanics. These letters are a most valuable contribution to the geologic literature of the first half of the century, and really laid the foundation to our knowledge of the dolomitic rocks.

In 1844 Studer, in a letter to the editor of Neues Jahrbuch,|| propounds the question whether dolomites may not be the product of isomerous carbonates being deposited together, the resultant taking the place of the calcium carbonate removed. Then Petzholdt examined for himself the dolomites of the Tyrol district ¶ and concluded that the view accepted by some of bitterspar pseudomorphosis was insufficient, but noted in a series of specimens taken from the successive layers that those representing the uppermost contained the most magnesium carbonate; indeed nearly the proportion for normal dolomite was reached in them, while the lowest layers were nearly pure calcium carbonate. A. v. Morlot recounted an interesting series of experiments to discover a chemical basis for a theory of the origin of dolomites.** The idea of a purely chemical origin should probably be expected at this stage; certainly we are not disappointed in finding it. Two years later Favre †† discussed an

* Compare Naumann Lehrbuch der Geognosie, Leipzig, second edition, vol. i, p. 764.

† Neues Jahrbuch für Mineralogie, 1847, p. 862. Auszug.

‡ Geol. Beschr. des Thüringer Waldgebirges, Theil ii, Abth. 5, 1806, pp. 99–121; also, Naumann Geognosie, cited, p. 764.

§ Mineralogisches Laschenbuch für das Jahr, 1824, pp. 239–506.

|| Neues Jahrbuch für Mineralogie, 1844, pp. 185–189.

¶ Ueber Dolomit-bildung. Neues Jahrbuch für Mineralogie, 1845, p. 722, Auszug.

** Neues Jahrbuch für Mineralogie, 1847, p. 862.

†† Neues Jahrbuch, 1849, p. 742. Auszug from Comptes Rendus, 1849, vol. xxviii, pp. 364–366.

experiment of Marignac and felt confirmed thereby in a chemical theory of the origin of dolomite. Calcium carbonate with a solution of magnesium sulphate was heated six hours to 200 degrees centigrade under a pressure of 15 atmospheres. The result was dolomite with a double carbonate of calcium and magnesium. Hydrochloric acid might be used in the experiment instead of sulphuric acid with a similar result in dolomite. The conclusion reached from the above experiment was that dolomite is found in the sea under similar conditions, namely, a temperature of 200 degrees, at a depth of 200 meters, at which depth the necessary pressure obtains. It is confessed, however, that this theory does not explain the porous condition of many dolomite beds. It is further difficult to understand how the necessary acid is developed and distributed throughout the sea; besides, deep-sea soundings made within the past twenty years have effectually proved that all hypotheses based on the assumption of a high temperature in the ocean abysses have no foundation.

Along this line of exposition Gustav Bischof's predilections led him as he investigated the carbonate rocks, and particularly the dolomites. It is not necessary to summarize his chapter on "Dolomite,"* for the last sentence but one tersely states his result:

"Taking into consideration all the facts known with regard to dolomite, so far as it occurs as a rock mass, it can only be regarded as a product of the alteration of limestone in the wet way, and there is no mode of alteration that is more probable than the substitution of carbonate of magnesia present in water for a portion of the carbonate of lime in limestone or the extraction of the greater part of carbonate of lime by the water permeating the limestone."

We shall have occasion to refer to this conclusion on another page.

In 1863 Dr T. Sterry Hunt expressed his opinion that—

"The carbonate of lime which the alkaline waters generally contain, being precipitated with the magnesian carbonate, the combination of these two subsequently gives rise to dolomite or to magnesian limestone." †

In his later writings Hunt opposes the theory that dolomite is formed by a partial replacement of lime in ordinary limestone—

"since beds of dolomite or more or less magnesian limestone are found alternating, sometimes in thin and repeated layers, with beds of non-magnesian carbonate of lime." ‡

In 1879 Henry Clifton Sorby,§ in his anniversary address, discussed the magnesian limestone of south Yorkshire and Nottinghamshire. He holds to the replacement theory, although he is commendably cautious, as this sentence shows: ||

* Elements of Chemical and Physical Geology, Paul's translation, 1859, vol. iii, pp. 155–203.

† Geology of Canada, 1863, p. 575.

‡ Mineral Physiology and Physiography, 1891, p. 171.

§ Quarterly Journal of the Geological Society, 1879, London, pp. 56–93.

|| Ibid., p. 85.

"That some chemical replacement did occur admits of no doubt; but it might be going further than the evidence warrants to conclude that the whole rock was entirely altered by true replacement without any direct chemical precipitation of magnesia."

From the foregoing brief tabulation—it cannot be assigned the dignity of a summary—of the leading literature of one hundred years on the dolomites it will be seen that some diversity of opinion has obtained; yet in considering it as a whole the consensus of search has been in the field of chemical geology. Occasionally an investigator would step into another field, but it was probably rather for the purpose of presenting a new view to his contemporaries than with any strong convictions that the results of his search would prove correct. The admirable summary of views presented by Naumann * and the later one by Zirkel † show a wider range of opinions than the writers can here give. Little has been done in the investigation of the carbonate rocks of this class since the paper of Sorby cited above beyond the examination of a few somewhat limited fields.

*Sediment-building.*—The phenomena of sediment-building in modern seas are much better understood now than formerly. The organic sediments are chiefly calcium carbonate, yet magnesian rocks, chloride of sodium, etcetera, occur. The quantity of calcium carbonate in the ocean receives constant additions from the land, the shells of mollusks, and other shell-secreting forms, and from disintegrating limestone cliffs along the seashore. Keeping pace with this accumulation is the constant withdrawal of material through the agency of organisms and, possibly, the formation of salts in which the components of calcium carbonate play a part; yet all the limestones formed from the calcium carbonate of the sea contain but a small proportion of other constituents.

*Contents of Seawater.*—In normal seawater there is a preponderance of magnesium salts over the salts of calcium. The chemists who investigated the material gathered by the *Challenger* found the following composition of the solids from seawater per 100 grammes of total salts. It is a mean of 85 samples:

| | | |
|---|---|---|
| Cl | 42.917 | (after basic O is deducted). |
| $SO_3$ | 6.415 | |
| CaO | 1.692 | |
| MgO | 6.214 | |
| $K_2O$ | 1.333 | |
| $Na_2O$ | 41.433 | |
| | 100.004 | |

* Lehrbuch der Geognosie, second edition, vol. i, pp. 763 et seq.
† Lehrbuch der Petrographie, Bonn, 1866, vol. i, pp. 234–252.

Dittmar * found strikingly similar results. He calculated them differently; Forchhammer * also.

DITTMAR.

| | |
|---|---|
| Cl | 100. |
| O | 22.561 |
| $SO_3$ | 11.576 |
| CaO | 3.053 |
| MgO | 11.212 |
| $K_2O$ | 2.405 |
| $Na_2O$ | 74.760 |

FORCHHAMMER.

| | |
|---|---|
| Cl | 100. |
| O | Equivalent not determined. |
| $SO_3$ | 11.88 |
| CaO | 2.93 |
| MgO | 11.03 |
| $K_2O$ | 1.93 |
| $Na_2O$ | Not determined. |

We see from the two series of investigations resulting in the above figures that the quantity of the magnesium salts is practically four times as great as that of calcium.

Thus in ordinary dolomites, taking into account the quantity of magnesium salts alone, the theory advanced by some that dolomite was formed by the addition of magnesium carbonate is both plausible and reasonable, provided the conditions were favorable for such addition; but it must be confessed that the writers have looked in vain for an example among the sedimentary deposits of modern and Mesozoic seas of such addition to the normal carbonate precipitates.

*Composition of modern Sea-deposits.*—Looking over the results of several investigations, we gather the following analyses of recently formed limestone rocks. They show a very low proportion of magnesium carbonate and other magnesium salts. Only the carbonate constituents of the several examples are given:

| | I. | II. | III. | IV. | V. |
|---|---|---|---|---|---|
| $CaCO_3$ | 83.99 | 98.26 | 92.80 | 95.00 | 92.51 |
| $MgCO_3$ | 1.04 | 1.38 † | 2.38 ‡ | 5.00 | 2.45 |

I. Analysis of coquina deposits at Saint Augustine, Florida. Charles P. Berkey, University of Minnesota.

II. Coral sand, straits of Balabac. Dana: Corals and Coral Islands, page 357.

III. Chalk from an elevated reef of Oahu. Dana: Corals and Coral Islands, page 358.

* H. M. S. *Challenger* Reports: Physics and Chemistry, vol. i, p. 23 *et seq.*

† $Al_2O_3$, 0.24.

‡ Other substances, 4.82.

IV. Dead coral taken from the beach. Darwin: Structure and Distribution of Coral Reefs, 1889, page 18. The figures given above are estimated. Darwin says that the quantity of carbonate of magnesia present in fresh coral is usually less than one per cent.

V. An average of the four preceding analyses.

Again, taking the results of the chemical analyses of five coquina gravels from Florida, analyzed by the United States Geological Survey, we see an average percentage of 3.82 magnesium carbonate given.* Fourteen specimens of coral rocks from the Hawaiian islands show an average of 4.52 per cent of magnesium carbonate †

So far as can be judged, the carbonate deposits of Paleozoic and Mesozoic times originally must have been essentially the same as the above. There is nothing in the anatomy of polyps, molluskoids and mollusks to lead one to believe that the progenitors of living forms were very different from their descendants whose structure and secretions are very well understood by zoölogists. It is therefore not an easy thing to imagine the formation of dolomite through any such process as that of modern limestone-building. Holding in view the Magnesian series, we are practically confined to the conviction that the accumulations of carbonate rocks in the central portion of the continent during early Paleozoic time were limestones of substantially the same constitution as those now forming within ocean areas. But they have become, quite universally, dolomites and dolomitic limestones. The transformation from limestones to dolomites must therefore be a subsequent process. Since there is always a percentage of magnesium carbonate in every limestone thus far known, there are two ways in which a dolomite may be formed: (1) By the deposition of more and more magnesium carbonate subsequent to the formation of the rock, and (2) by the gradual removal of calcium carbonate from the rock mass.‡

There are many reasons for believing that the first method did not obtain in the region under consideration. The corroded condition of the beds at many localities where they are well exposed, the porous state so generally seen in all three of the dolomitic formations, the readiness with which the cliffs along the river gorges retreat from the streams in vertical, castellated walls until valleys miles in width are formed, are phenomena opposed to the view that the beds were increased in bulk. These conditions were all seen and described for other regions by Leopold v. Buch more than seventy years ago,§ although the real cause of the phenomena was not clearly understood.

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* Report of Work: Chemistry and Physics, Bulletin no. 60, 1890, p. 162.

† Ibid., p. 164.

‡ Compare Irving: Chemical and Physical Studies in the Metamorphism of Rocks, 1889, p. 71.

§ See Taschenbuch für Mineralogie, 1824, pp. 244, 257, 283, etc.

*Composition of spring and other Waters.*—Attention has already been directed to the existing conditions of continental drainage. The present rainfall throughout the area of the Magnesian series will average about 30 inches per annum. If one-third of this, as meteorologists estimate, soaks into the ground, there is an enormous percolation. This water may not all pass through the rocks under discussion, but that much of it does is proved by the many springs issuing from the rocks throughout their entire extent. The composition of these spring waters, together with those of a few springs from the glacial drift, without any positive proof that they come in contact with other carbonate masses than the pebbles lying among the drift debris, may be thus summarized:

1. An average of seven mineral springs of Wisconsin gives in grains per gallon, $CaCO_3$, 12.640; $MgCO_3$, 8.981.

2. An average of seven mineral springs of Minnesota gives in grains per gallon, $CaCO_3$, 9.250; $MgCO_3$, 4.043.

3. An average of six artesian wells of Iowa gives in grains per gallon, $CaCO_3$, 13.085; $MgCO_3$, 5.678.

4. An average of four lakes and rivers in Minnesota gives in grains per gallon, $CaCO_3$, 6.102; $MgCO_3$, 3.332.

It will be seen from the above figures that, gathered from every condition of occurrence, the natural waters of the region underlain by the Magnesian series are yielding a greater proportion of calcium carbonate than of magnesium carbonate.

*Analyses of Travertine and impure Coral.*—Again, taking into consideration the deposits from these waters, the results are even more marked. Very often travertine is deposited. Mr C. P. Berkey, of the University of Minnesota, analyzed two specimens—one deposited by waters discharged from Trenton limestone at Minneapolis, Minnesota, with Trenton shales and glacial drift débris above; the other discharged from Saint Lawrence dolomitic shales at Osceola, Wisconsin, with Jordan sandstone, Oneota dolomite and glacial drift above—with this result:

| | Minneapolis travertine. | Osceola travertine. |
|---|---|---|
| $CaCO_3$ | 98.01 per cent. | 98.20 per cent. |
| $MgCO_3$ | 1.44 " | 1.75 " |
| | 99.45 " | 99.95 " |

There is no reason to suppose that the solvent power of water is any different now than it has been in any geologic period since the Paleozoic era. The inevitable result of such solvent action is to reduce the proportion of $CaCO_3$ remaining in the rocks constantly toward that found in normal dolomite. That the condition of a normal dolomite has not yet been reached may legitimately be inferred from the chemical composition of the solid contents of the waters, as shown in the figures above; it

is also proved by chemical analyses of the rocks themselves, many examples* of which have elsewhere been brought together.

In contrast with the results obtained from the foregoing specimens, which seem to be normal deposits for the material given, we note in some exceptional cases quite different results. George Hughes reports† from the island Aruba, West Indies, a mass of phosphatized coral whole cargoes of which will test over 76 per cent of calcium phosphate. Dana‡ also noted on Howland's island a pseudomorph consisting of phosphatized coral yielding 70 per cent of calcium phosphate. The same author§ also found in the coral island of Mateo a sample which yielded $CaCO_3$ 61.93 per cent and $MgCO_3$ 38.07 per cent. This was probably deposited in a lagoon where the several magnesium salts of the water must fall down as precipitates, as the inclosed water was repeatedly evaporated.

*Geographic Considerations.*—The geographic conditions of any area must be taken into account in searching out geologic details. The position with reference to the sealevel is an especially important one.

*Continental Movements.*—There is much evidence to show that the central area of the North American continent has been uplifted above the sea for a large portion of the time since the closing epochs of the Paleozoic era. What can take place in accumulations lying fathoms below the sealevel geologists and chemists are not yet completely able to say, but where any marked changes are found to occur it is difficult to conceive of their not having involved the addition of material and a thickening of the strata. Districts may be cited where within recent geologic times probably no material change has taken place. The Austin limestone of Texas shows in three analyses reported by the state survey‖ only a trace of magnesium salts. In another place it is reported that the Austin-Dallas chalk varies from 85 per cent to 94 per cent calcium carbonate and 2½ per cent, more or less, of magnesium carbonate,¶ as calculated from the analysis of the rock at hand. The above are cited as instances—perhaps fair ones, yet in some respects parallel ones—of a Mesozoic limestone which was accumulated and probably kept below the surface of the sea much of the time until the Pleistocene epoch. It is as a formation of great extent and of universally horizontal position that it has been raised to its present altitude. With the beginning of the existing conditions a new series of chemical phenomena is opened whose

* Bull. Geol. Soc. Am., vol. 3, 1892, p. 348.

† Quarterly Journal of the Geological Society, 1885, vol. xli, p 81.

‡ Corals and Coral Islands, 1874, p. 293.

§ Ibid., pp. 349, 357.

‖ Geological Survey of Texas, Third Ann. Rep., 1891, pp. 351–354.

¶ First Ann. Rep. Geol. Survey of Texas, 1890, p. 113.

result can now be only conjectured. In forming that conjecture geologists may note the beds of the Magnesian Series as they exist today after having remained raised above the sea for a time much longer than that involved in the accumulation and covering with Upper Cretaceous and successive Tertiary beds of the Middle Cretaceous limestones of Texas.*

*Removal of Calcium Carbonate and its Effects.*—Thus we see that to bring the Magnesian Series into their present chemical condition an enormous reduction in the quantity of calcium carbonate, and consequently in the bulk of the formations, must be assumed. No figures are possible which will more than approximate to accuracy.

Elie de Beaumont calculated that the removal of every other molecule of $CaCO_3$ and its replacement by a molecule of $MgCO_3$ would reduce the volume of the mass to the extent of 12.1 per cent.† Thus every 100 feet of the present thickness of the Oneota formation would represent an original thickness approaching 112 feet, since it has not yet become a typical dolomite.

While de Beaumont's calculation might prove a very reasonable one for certain localities, the conditions which obtain in the northwestern states do not appear to conform to such a theory. Even if the dolomites were formed in the deep sea, as some investigators assume, the long and constant separation of the calcium carbonate, continuous since the elevation of the rocks above the sealevel, effected through the agency of percolating waters and now going on, would have reduced the beds to a very great extent from their original or acquired chemical and physical conditions. But de Beaumont's theory of molecular replacement is not satisfying. It is difficult to understand from whence came the enormous quantities of magnesium carbonate which was necessary for such continent-wide replacement as must have taken place if all the Paleozoic dolomites known to geologists were formed in that way. It is equally difficult to understand how the replacement on such a broad plan could have been carried on beneath the sea at great depths.

Geikie also very strongly hints that the cavernous condition shown by many dolomites is not sufficiently accounted for by this calculation.

The porous condition of the dolomites under consideration has already been pointed out. This character was considered by Professor Dodge in his examination of the physical characters of the Minnesota building stones.‡ It is found that the average increase of weight by a four days' saturation in water in the case of ten samples of dolomites and dolomitic

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* E. T. Dumble: Geology of the Valley of the Middle Rio Grande, Bull. Geol. Soc. Am., vol. 3, p. 230. Dumble makes the Austin beds the lowest limestone of the Upper Cretaceous of the Colorado section.

† Geikie: Text-book of Geology, third edition, 1893, p. 321.

‡ Geol. and Nat. Hist. Survey of Minn., Final Rep., vol. i, pp. 195–203.

limestones was 3.11 per cent. The difference in specific gravity between water and ordinary compact dolomite would raise this to near 9 per cent of actual bulk. If, in considering limestone and dolomite in the mass and in molecules, bulk were the same, 9 per cent of the limestone contents of these formations might be counted out in calculating the reduction in thickness of the beds. It is not necessary in this summary to present tables of calculations. The flow of waters from the dolomitic beds, with their load of calcium carbonate, can in time produce but one result, and that is to bring into more equal proportions the quantity of calcium and magnesium carbonates. The disappearance of over 80 per cent more of the former than of the latter, which occurs if the original rocks of these beds had the composition of average modern marine deposits,* must result in the removal of at least eight times as much of that material as remains behind. Under such an assumption every 100 feet of the present thickness of the Oneota and Shakopee would represent an original thickness of 1,000 feet, more or less, an extent much nearer in accord with what seems necessary in sedimentary accumulation to conform to the profound faunal changes and crustal movements so conclusively proved by the paleontologic and structural conditions of the rocks.

Further, that much reduction has taken place in the sandstones and arenaceous shales of the Magnesian series is shown in the remarkable freedom of these rocks from the several impurities so universal in recent rocks of this character. So far as erosion has disclosed them, the granitic and quartzitic rocks, the source of these sandstones, contained these impurities to as high an extent as the same rock species in any other region.

### *BASIS OF THE DISCUSSION.*

In this discussion the authors have not attempted to advance any new theory of the origin of dolomites and dolomitic limestones. The simple question before them has been this: Cannot the great reduction in bulk, the pronounced changes in chemical composition and physical characters which the dolomites of the region studied have undergone, be explained through the operation of such forces and processes as are to be seen going on at the present time?

## SUMMARY.

The Magnesian series discussed in the foregoing pages consists of four alternating formations of dolomites and sandstones belonging to the Upper Cambrian and a fifth of dolomite which, on paleontologic grounds when its fauna shall be studied, may be considered a part of the Ordovician.

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*See ante, p. 192.

The paleontologic evidence bearing on the classification arrived at by the authors may be stated categorically as follows:

1. Between the Saint Lawrence and the underlying Potsdam sandstone (Dresbach sandstone, page 170), there is a faunal break which, so far as known to the writers, is complete.

2. The Saint Lawrence, Jordan and Oneota have a large proportion of their known species in common, as, for example, *Orthis pepina*, Hall; *Raphistoma minnesotensis*, Owen.

3. Between the Oneota and Shakopee there is a faunal break over which no species passes.

4. Between the Shakopee and the overlying Saint Peter sandstone there is another faunal break over which no species passes.

There are, therefore, at least three faunas in the northwestern states between the Algonkian and the Saint Peter subdivision of the Ordovician.

The geographic distribution of the Magnesian series is then outlined from the field-notes of the authors, and reasons for the nomenclature of the several subdivisions are to some extent discussed. The characters which led to the classification of former writers are pointed out and the faunal types of the several formations are named.

The lithology of the series is next discussed and the clean, pure condition of the sandstone formations shown, together with local cementation of the grains with calcite, which on fracture discloses the crystallographic continuity under which it was deposited. Enlargement of quartz grains is shown to be frequent. The dolomites also assume interesting lithologic characters. The development of rhombohedral grains is a general tendency. Among the impurities present are silicious oölite and glauconite. The latter has every evidence of secondary origin rather than primary, as is sometimes thought.

In the closing pages of the paper the genesis of the series is considered. The sandstone is assumed to have originated in essentially the same way as that of more recent geologic times and of less chemically pure composition. In discussing the genesis of the dolomites the writers seek to find in natural and every-day processes familiar to geologists the mode of formation of these extensive beds. They do not attempt to explain it through the addition of vast amounts of magnesium carbonate, because no source can be thought of as conforming to all the physical and paleontologic facts; but noting the great reduction in the thickness; the successive yet distinct faunas which the Magnesian series carries, and, finally, the present rapid removal of calcium carbonate as compared with magnesium carbonate through the agency of percolating waters, they conclude that it has been chiefly through the removal of calcium carbonate that the present dolomitic condition has been reached.

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# RECENT GLACIAL STUDIES IN GREENLAND

ANNUAL ADDRESS BY THE PRESIDENT, T. C. CHAMBERLIN

*(Read before the Society December 28, 1894)*

CONTENTS



## INTRODUCTION.

Our Society is still young and uncontrolled by precedents. The hope has been expressed that if precedents shall become established they may be expressions of freedom and individuality rather than of limitation and monotony. It has been thought that if the presidential address shall be confined to reviews and summaries and restricted to special

modes of presentation it may become more perfunctory than vital. To whatever practices your collective preferences may at length lead, I trust that between these expressed wishes and the liberties conceded to our youthfulness I shall have your sanction or, at least, your pardon if I occupy your attention with a sketch of personal studies on the glaciation of Greenland made during the past summer. I further hope that if in presentation I invoke the aid of physical illumination to supplement the dimness of my own it will not awaken your displeasure.

### Object of the Studies.

The purpose of these studies was to find light upon some of the obscure problems of our Pleistocene glaciation. No hope of covering the whole field was entertained. Attention was therefore concentrated upon points thought to be most promising of instruction.

The foremost questions at the outset were: How does a glacier take up its material? How does it carry it forward? How does it put it down? What functions do water and topography play in the process? A glacier's methods in respect to lateral and medial moraines, which are superficial, are simple and well known. Its methods respecting basal material, which is largely concealed, constitute the problem. The locus of study was controlled by these questions. The summits of the glaciers were but lightly reconnoitered. Their bases were as closely scrutinized as possible. The snowy heights are indeed alluring, and in the inspiring air of the northern fields one loves to mount, but light on our drift is to be sought in the dirt and drip and shadows of the bottom. The darkest spots are here the fullest of light.

In the end these leading questions were compelled to yield much of their dominance to others which grew to scarcely less vital importance.

### Distribution of the Studies.

In a geographic sense, the studies fall into three groups:

1. A cursory scrutiny of the coast between cape Desolation and Inglefield gulf, a stretch of above a thousand miles, to note the effects of former glaciation.

2. A brief inspection of three local glaciers on Disco island, near the Arctic circle, for comparison.

3. A study of the inland ice, local ice-caps, and fourteen derivative glaciers about Inglefield gulf, between latitudes 77 and 78 degrees.

### Comparison between Glaciation of Mainland and Greenland.

In a comparison between our former glaciation and the present glaciation of Greenland two elements of difference are to be recognized. The first relates to topography, the second to latitude.

Our drift, except on the eastern border and the Cordilleran tract, is spread upon a vast plain. The ice-fields of Greenland rest mainly upon plateaus fringed by rugged mountains. To learn how a Greenlandic glacier would behave on our plains the effects of broken topography must be escaped or eliminated. Simple elevation, however, is immaterial. A plateau of smooth surface may furnish conditions identical with a plain, so far as glacier behavior is concerned. It is only necessary that the glacier deploy freely on relatively smooth ground and come to a limit by the balance of growth and wastage. It was extremely desirable, therefore, to find a portion of Greenland whose border was free from mountains. Inglefield gulf, perhaps better than any other portion of Greenland, furnishes the desired conditions. Unlike most of the coast, it is not girt by mountains. The borderland is a plateau about 2,000 feet above the level of the sea, with a summit-plain of marked uniformity. Its undulations are intermediate in strength between those of the eastern and western parts of our own glacial field. The border of the great ice-sheet may there be studied on relatively smooth ground, or it may be studied on undulatory ground, or the lobes or tongues that descend into the valleys may be chosen. In the portion in which my chief studies lay only a very small fraction of the ice was discharged into the sea. The border would in no appreciable way be changed were there no sea-wastage at all. Glacial tongues from one to three miles long are frequent, but it does not appear that the nature of the main ice-border would be essentially different if the valleys that caused these tongues had been absent.

The peninsulas of the region have local ice-caps from which glaciers radiate as from the great ice-cap. The habits of the small and the great ice-caps are essentially the same.

Of the 30 or 40 glacial tongues which descend toward Inglefield gulf less than one-third reach the shore, and scarcely one-half of these discharge notable icebergs. The majority terminate in valleys whose bottoms are formed of glacial debris and whose lower gradients are moderate.

### Relation of geologic Formations of Greenland to Glaciation.

The geologic formations of Greenland are unfavorable in the main to glacial studies. The nearly universal presence of the ancient gneissic series makes discrimination of the origin of material unsatisfactory, when it is not impossible. Besides this, the debris is rocky and arenaceous; the clayey element is scant.

In the Disco and Inglefield gulf regions, however, the gneissic series is bordered by clastic and igneous beds that give some relief from these adverse conditions. On Disco island there is a nucleus of gneiss sur-

rounded by basalt and sandstones. About Inglefield gulf the gneissic series is covered by thick terranes of sandstone and shale which are traversed by basic dikes. The clastic series forms but a border, and is only reached by the ice near its edge. It is thus possible to tell how late the erratics from it were introduced into the ice, what courses they pursued, and what actions they suffered.

### The Effects of Latitude on Glaciation.

In so far as latitude is merely an agent of glacial temperatures, it is not necessary to consider its effects, for some equivalent cause of glacial temperatures must have been operative in Pleistocene times. It is only the distinctive results, such as may be attributed to the constancy of the sun above or below the horizon, the low angle of incidence of its rays, their impact from all points of the compass, and similar features, which need to be considered.

A partial means of determining what these are is found by comparison between the glaciers of Disco island, only a little within the Arctic circle, and those of Inglefield gulf, 8½ degrees farther north. The Disco glaciers seem to have all the familiar characteristics of glaciers south of the Arctic circle, while the Inglefield glaciers take on habits significant of their high latitude. This will appear as we pass on.

### Verticality of the Glacial Margin.

The feature which is likely first to impress the observer, on reaching the glaciers of the north, is the verticality of their walls. Southern glaciers, as you are aware, terminate in curving slopes, and the Disco glaciers of middle Greenland have the same habit; but the margins of the Inglefield glaciers rise abruptly like an escarpment of rock, 100 or 150 feet or more. The layers of ice are cut sharp across, exposing their edges. This verticality has been observed by Greely, Heilprin and others. It is not quite universal, however, as sloping forms occur here and there. Occasionally a glacier presents both aspects. These abrupt terminal walls turn toward all points of the compass. It is perhaps too much to say that they do this indifferently, as but few glaciers facing the north were seen, but among these verticality prevailed much as elsewhere. (Figures 1 and 2, plate 3.)

The cause, with little doubt, is the low inclination of the sun's rays and their impact from all points of azimuth in succession. Rays of low slant strike the back of a glacier at a very acute angle and glance away with the greatest facility and the least effect. On the edge of the glacier, however, they strike more vertically and effectively. In addition to this, the slanting

FIGURE 1.—WEST FACE OF BRYANT GLACIER.

Showing vertical wall and stratification of the ice. The amount of debris is made to appear much greater than it really is by surface wash.

FIGURE 2.—FRONT OF BRYANT GLACIER.

Showing vertical wall and stratification of the ice.

BRYANT GLACIER.

rays, touching the surrounding earth's surface at low angles, are reflected at like low angles, and hence often impinge upon the edge of the ice. On a lake, just before sunset, you have doubtless often seen a brilliant illustration of the wide space from which rays of low slant are reflected so as to be caught by an object of slight elevation. Prominences about the glaciers catch and absorb the heat on their sides rather than their summits, and in turn radiate this heat in lines chiefly normal to their walls and favorable to reception by the edges of adjacent glaciers. It appears, therefore, that a larger proportion of the sun's rays falls on the glacier edges at the north than at the south, and it is the proportion of rays that determines the contour. It is interesting to note in this connection that nunataks are often surrounded, like an ancient castle, by a moat sunk between the foot of the eminence and the mass of the glacier, whose face is usually vertical. It is only when the movement of the ice is notably great that it presses hard against the nunataks. We must not, however, fall into the error of supposing that verticality is due simply to reflection from cliffs, because glaciers that end on broad, smooth, gravel-bottomed valleys are as vertical as any. Here it must be the direct rays and the rays reflected from the smooth surface of the valley which produce the effect.

## Stratification.

*General Characteristics.*—Next to verticality, the most impressive feature is the pronounced stratification of the ice. The stratification of glaciers is not new, but the extent, definiteness and peculiar characteristics displayed by its phenomenal exposure in these northern regions are perhaps in some measure a revelation. The ice is almost as distinctly bedded and laminated as sedimentary rock. The vertical face usually presents two great divisions—an upper tract of thick, obscurely laminated layers of nearly white ice and a lower laminated tract discolored by debris. At the base there is usually a talus-slope, and sometimes, but only sometimes, a typical moraine. In the upper portion bluish solid layers separate the more porous ice into minor divisions, and these are grouped by consolidation into more massive layers. Sometimes the whole upper division consists of a single stratum, but more commonly it is divided into several great beds separated by quite distinct planes. (Figures 1 and 2, plate 3, and figure 3, plate 4.)

The lower discolored division also sometimes consists of one great stratum, but oftener it is divided into several great layers, as in the case of the white ice above. Very numerous partings further divide these beds into minor layers of varying thickness, grading down into delicate laminations, a dozen or a score to an inch. In addition to the bluish bands and the physical partings found above, there are here interstratified

layers of debris, which embrace not only sand and silt, but rubble and bowlders. The whole may be likened to a cold sandwich—a meat and mustard of drift spread between slices of ice. Often the interspread layer consists of the merest film of silt; at other times it attains a thickness of an inch or two, and sometimes it reaches several feet; but this is rare, and it is then usually a heterogeneous mixture of debris and ice. The debris is usually arranged in very definite and limited horizons, leaving the ice on either hand as clean and pure as any other. It is very notable and significant that the ice next to the debris-layers is the firmest and most perfect ice which the glacier affords. It fractures in sharp, vitreous partings, which send forth beautiful iridescent reflections like the purest lake-ice. Seen in place, it appears black because of the dark earth above and below it, but separated from these associations it shows its true nature as clear, transparent ice. Even this ice, however, does not reach the perfection of ice-structure, but it is further advanced toward it than the great mass of the glacier.

*Debris-layers and Laminæ.*—The coarser debris is arranged in the same horizons with the fine debris. Often a fragment of rock will be several times as thick as the average silt-layer with which it is associated. In this case it is usually centered on the layer and projects above and below into the clean ice. In this way bowlders of considerable dimensions may be associated with a mere film of fine debris. More frequently, perhaps, the larger fragments are associated with laminated bands rather than with single laminæ, and in this case it is interesting to observe that a portion of the laminæ curve downward and pass under the bowlder, while another portion curve up over it. Sometimes all the laminæ part and pass around on either side; in other cases those which encounter the center of the bowlder terminate there. Usually corresponding laminæ appear on the other side. The phenomenon is almost precisely like the behavior of silt-laminæ in stony sediments. (Figure 4, plate 4, and figure 13, plate 9.)

The debris-layers are not at all uniform in their distribution. Often they have much regularity and persistence; often they thin out and disappear within a short distance; more often still they persist for a few rods and are replaced by adjoining layers which come in as these thin out. Thus a belt of layers has much persistence, while the constituent layers are freely entering and vanishing. Lenses of debris occasionally appear among the layers, and a doubling back of the layers upon themselves, giving a lenticular section, is not uncommon.

The laminæ are sometimes very symmetric, straight and parallel, but often they are wavy and undulatory. In many instances they are greatly curved and sometimes contorted in an intricate fashion. As Dr. E. von

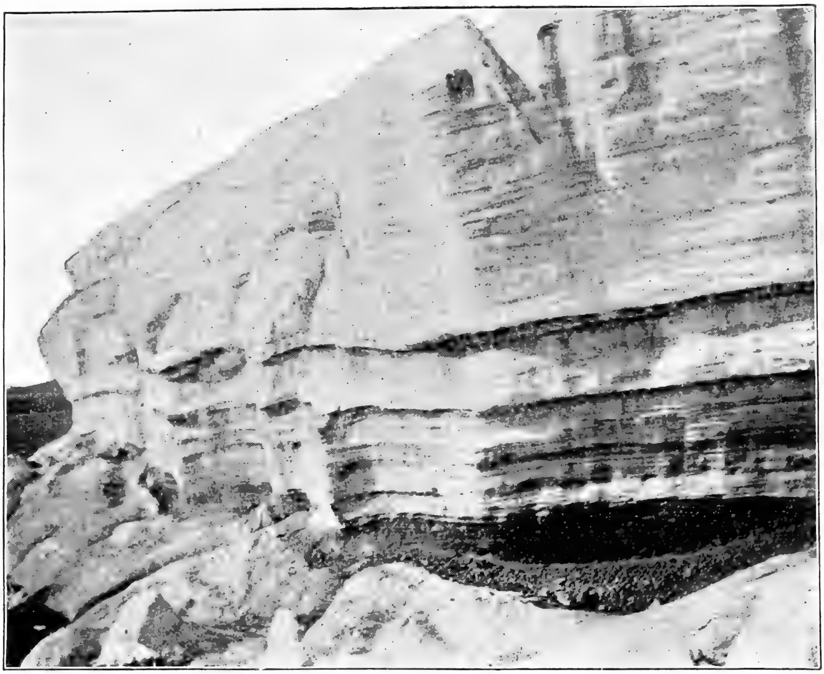

FIGURE 3.—EAST FACE OF BRYANT GLACIER.

Showing vertical wall and stratification of the ice.

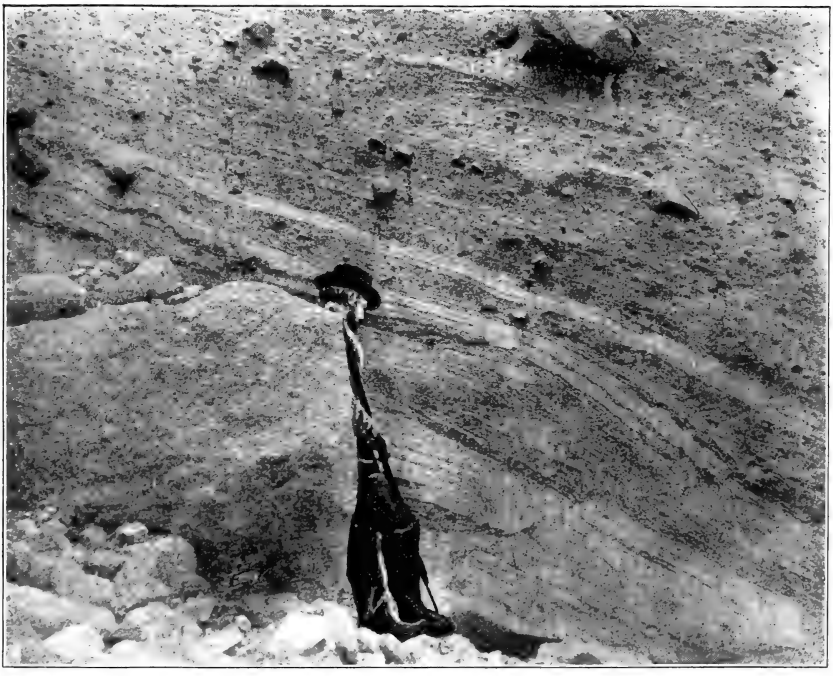

FIGURE 4.—LOWER PART OF VERTICAL WALL OF GABLE GLACIER.

Showing inset debris, lamination, faulting and drag.

BRYANT AND GABLE GLACIERS.

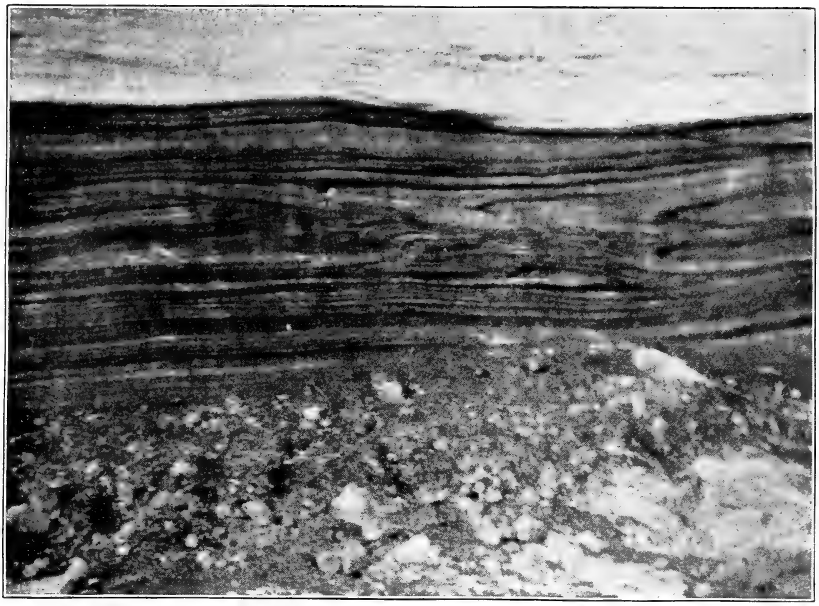

Figure 5.—Lower Part of Portion of east Wall of Bowdoin Glacier.

Showing lamination, faulting, drag and overjutting of layers.

Figure 6.—A Portion of east Face of Bowdoin Glacier.

Showing an oblique upward thrust and distortion of laminæ.

BOWDOIN GLACIER.

Drygalski has remarked, they closely simulate the foliation and contortion of gneiss. Indeed, the whole structure is perhaps as well described by the term "foliation" as by any other in common use. (Figure 6, plate 5.)

The debris belts are essentially parallel to the base of the glacier. They are chiefly confined to the lower 50 or 75 feet; sometimes they prevail up to 100 feet and rarely beyond. I think 150 feet might be named as a rather extreme limit. They are more abundant at the sides of the lobes than in the center, a fact that is significant in indicating the introduction of a notable part of the debris after the lobes were formed. In consonance with this, the debris appears to be most abundant in the glacier-lobes which descend as cataracts or crowd between closely hugging cliffs. If, standing in front of a glacial lobe, the dirt bands are traced, many will be found disappearing toward the axis of the lobe. If, standing on the side, they are traced upward, many will be found disappearing at the cataracts or at the embossments of the bottom or at spurs on the sides.

In meeting obstacles in front, the basal beds have the habit of curving upward, carrying their debris with them. Terminal moraines are sometimes thus made, resting on the edges of the ice-layers which formed them.

In front of obstacles the layers are sometimes simply curved upward and pass over the prominence; but if the frontal slope be steep, much crumpling of the laminæ may take place. (Figure 13, plate 9.)

*Faulting.*—Not only are the foliations twisted in gneissic fashion, but they are fractured and faulted, and along the fault-line the laminæ are effected by drag precisely analogous to that found in faulted rocks. (Figure 5, plate 5.)

*Origin of the Stratification.*—Two classes of phenomena are obviously embraced in the stratification, the one relating to the bedding of the ice irrespective of the debris-layers, the other relating to the introduction of them. The first is a general phenomenon; the second is superinduced.

Beyond serious question, the general stratification had its initial stages in the original snowfalls. Whenever encrustment intervened between one fall and another, a layer of more or less definiteness resulted. Whenever a succession of falls was followed by a period of encrustment, a more complex and massive layer was formed. The seasons doubtless developed annual subdivisions, and possibly, at intervals of a few years, unusual summer effects bound the deposits of a succession of years into a great stratum. It is the testimony of Lieutenant Peary and his associates that the surface of the ice-cap, under the action of the great windstorms, becomes marble-like in solidity and texture, as well as in color. At the same time the erosion of the wind develops sastrugi, which further

differentiates the accumulating snow. In view of these varied agencies of stratification, it is doubtful if we can look with any confidence for criteria by which the annual snowfall can be safely distinguished from that of other periods.

The original stratification could not have been very pronounced. Perhaps it was intensified somewhat during subsequent consolidation, but some new agency was necessary to produce the more definite partings and to introduce the layers of debris. This agency appears to have been a shearing movement between the layers. On almost every one of the vertical faces certain layers jut out sharply over those beneath. Sometimes there are six, eight or ten of these projections, one above another, ranging from a few inches to one or two feet. In rare cases the projection reaches eight, ten or fifteen feet. At first sight this seemed clear proof of a shearing motion,* but upon more critical study it was ascertained that there was usually earthy matter in the upper part of the under layer which caught the sunlight and was melted back faster than the pure ice above, and suspicion arose that the whole phenomenon might be attributed to differential melting under the influence of the very oblique rays of the sun. In following a given projection laterally, it often terminated where the earthy impregnation ceased. Of course, the shearing and the impregnation might have been companion phenomena due to a common cause, but the observation gave ground for doubt as to the trustworthiness of this class of evidence. More direct proof was sought in the grooves or flutings, which it was supposed erratics, lying in the junction or inequalities of the layers, might produce. The search met with apparent success. Fluted surfaces were found. The under surfaces of many of the overprojecting beds were fluted, and, at first sight, this seemed to give abundant and incontestable evidence of shearing, but here again more careful study made it appear quite certain that much of this fluting was due to the water which trickled down the face of the overlying layer. Instead of dripping freely away when it reached the edge of the ice-cornice, it followed the under surface backward and fluted it. In most cases I could not tell whether the fluting had been initiated by shearing and merely developed by the water or not. In searching for fluting not attributable to water-action I found instances where the junction-plane marked by debris was itself fluted, the earthy material passing backward between the layers in a corrugated form.

Another class of evidence was found in the fallen blocks of stratified ice which had entered upon the initial stages of disintegration sufficiently

*The term "shearing" is used in this discussion in its common mechanical sense, signifying differential movement along a plane, and not in the ultra-physical sense, which embraces all movements of particles upon each other, even those of liquids and gases.

FIGURE 7.—PORTION OF SOUTHEAST FACE OF TUKTOO GLACIER.

Showing projection of the upper layers, apparently due to overthrust

FIGURE 8.—PORTION OF SOUTHEAST FACE OF TUKTOO GLACIER.

Showing projection of the upper layers and the fluting of their under surfaces.

TUKTOO GLACIER.

FIGURE 9.—PORTION OF NORTH SIDE OF GABLE GLACIER.

View is near junction with main ice-cap and shows method of inthrust of debris-layers.

FIGURE 10.—PORTION OF NORTH SIDE OF GABLE GLACIER.

The view is taken below the one above, and shows an overthrust with debris along the plane of contact; ice much veined.

GABLE GLACIER.

to disclose the intimate nature of their mass. Definite planes of parting were developed between some of the layers. This was often true even when the layers were not separated by any earthy filament, the ice on both sides being white and pure. The plane of parting between the layers was often slightly gaping at the surface; sometimes the two layers seemed to be peeling apart. I found it easy by a moderate stroke of the spike of my alpenstock to split blocks along these partings. The separated blocks presented smooth surfaces, which seemed to leave no question of their analogy to slickensides. The layers on either side were made up of coarse granules of ice, intimately interlocked, so that an attempt to cleave the mass at other points resulted in a fracture of the most ragged and irregular sort.

But the best evidence of the verity of shearing between the ice-plates lies in the intrusion of the earthy material itself. I was fortunate enough, unless I misinterpret, to observe the actual process of intrusion. The best illustration was found on the north side of a short lobe of the great ice-cap designated the Gable glacier. Just back of the point of observation there was a large embossment of rock, which expressed itself at the surface of the ice by a beautiful halfdome, like the Halfdome of the Yosemite. The other half of the dome was cut away, revealing the operations at the base within. Here it was observed that trains of debris, apparently rubbed from the surface of the embossment, were being carried out almost horizontally into the ice in its lee. Some of these were short, while others extended several rods into the ice. They were somewhat inclined downward, but the slope of the glacier being greater, they passed out into the body instead of following the base of the ice. At one point the overthrust reached such a degree as to carry the earthy layers obliquely almost across the thickness of the glacier, producing a pronounced unconformity. The illustrations will show these phenomena with an accuracy and vividness quite beyond the power of a verbal description. (Figures 9 and 10, plate 7.)

On the East Branch glacier a similar phenomenon was observed below a cataract of the ordinary type. Here tongues of debris, having their origin in the bowlder-clay below the glacier, were seen to reach out into the basal portion of the ice as though they were being introduced into it by the differential movement of the layers upon each other. The mode of operation seems to be this: When the ice is forced over a prominence it settles down a little in its lee, and is then protected somewhat from the thrust of the ice behind; the next ice that passes over, being prevented by the former portion from settling down at once, is thrust forward over it. To some extent this is accomplished by the bending and doubling of the layers and to some extent by distinct shearing. At length, however,

the first layer is compelled by the general friction to move somewhat forward, and in time to join the common moving mass, carrying the overthrust layer of debris between it and the ice-layer above. The way is then opened for a repetition of the process. This picture of the behavior of the ice is quite radically different from that entertained by the viscous hypothesis, in which the ice is supposed to flow down the lee side of a prominence, as if it were liquid. The motive power here seems not so much gravitation pulling a fluent body forward as the thrust of a rigid body by a force in the rear.

*Behavior of the Ice in passing over low Prominences.*—Several excellent opportunities for observing the behavior of ice in passing over low embossments were offered. From the front of the embossment there originated laminæ which extended backward with a graceful, arching curve, much like the profile of a drumlin. A portion of the ice remained between these curving laminations and the upper and rear portion of the embossment. After reaching a point in the rear of the embossment, the laminæ curved downward with increasing rapidity until well in the lee, when they turned about at a more or less sharp curve, or even angle, and ran backward to some point not far in the rear of the embossment, where they ended. The higher laminæ made the longest curves and had the sharpest angles in the lee of the embossment. It appears obvious that the ice in the lee of the embossment moved more slowly than that above; hence the doubling of the laminæ upon themselves. It appeared upon close inspection that some of the inthrust layers described above consist in reality of very sharply reduplicated laminæ. It seems, therefore, that this phenomenon grades insensibly into the preceding. A study of laminæ not associated with embossments showed many signs of doubling upon themselves in a similar way. It appears, then, that there is a gradation from laminæ that simply suffered doubling up to layers that obviously sheared upon each other and produced manifest unconformity by pronounced overthrust. (Figures 11 and 12, plate 8; also figure 9, plate 7.)

*Development of blue Bands.*—Some of the laminæ observed to originate on the brow of embossments of rock were simply blue bands. They were even seen on bowlders underlying the ice. So far as observed, the blue bands started at some little projection or rugosity in the brow of the embossment. From this point they extended rearward, usually curving a little upward and free from the embossment, following a drumloidal curve until they had passed its lee, when they turned downward and sometimes returned as described above. Now, it is interesting to note that within the curved loop in the lee of the embossment I observed in one instance several nearly vertical blue bands, standing parallel to each

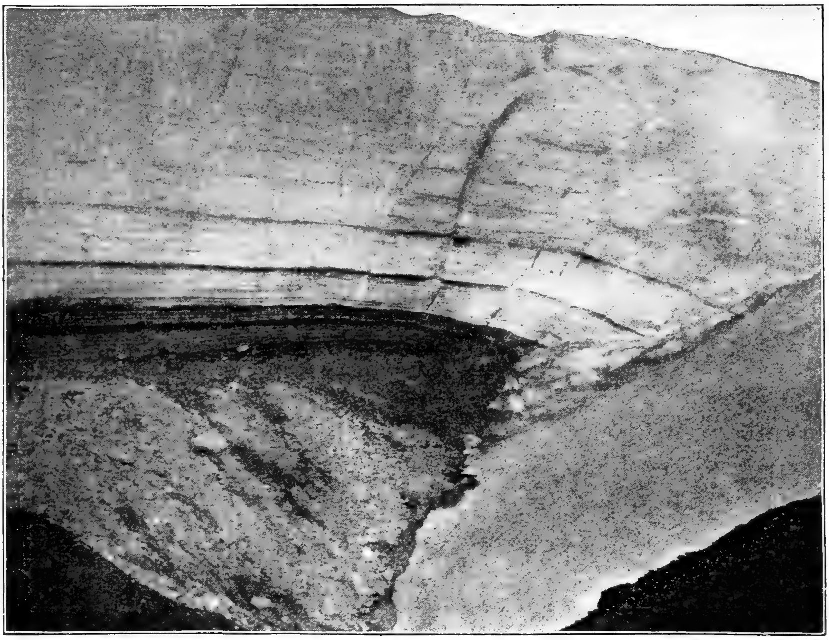

Figure 11.—Portion of east Side of Fan Glacier.

Showing behavior of the ice in passing over a low embossment of rock and drift. This figure shows only the upper portion, the next only the lower portion; the central part, of about equal length, not shown. Motion from right to left.

Figure 12.—Lower Portion of above view of Fan Glacier.

Showing the curving down and bending back of the laminæ in the lee of the embossment. The prominent dark line in the center turns back with a sharp curve a short distance beyond the limits of the view, and is apparently continuous with one of the bands shown very obscurely in the lower left-hand portion of the picture.

FAN GLACIER.

other and stretching part way across the space embraced in the loop. Here it would seem that the blue bands are produced by the exceptional pressure of the ice in moving over rugosities on the brow of the emboss-ment, and that their position in the ice is parallel to the ice-movement, while at the same time blue bands may also be developed nearly at right angles, after the analogy of slaty cleavage.

It has already been remarked that the most solid ice was usually observed in immediate association with the laminæ of earthy matter. The inference is, therefore, that the agencies which introduced the earthy material by the same act developed solid ice. Independently of either of these forms, it appeared to be beyond serious question that solidified layers of ice were developed out of the crusts of the original snow, and hence that a variety of the bands is a direct derivative of the original stratification. In so far as the general shearing of the strata upon each other takes place independently of the special process by which earth was introduced, to that extent, I judge, the faces which moved over each other developed greater solidity than the adjacent parts and approached the more perfect ice of the blue bands. I am not sure that these observations traverse in any serious way the current doctrine, which we owe to Tyndall, that the blue bands are chiefly the product of pressure in constricted portions of the glaciers or in the descent of cataracts, but they do suggest that this doctrine needs limitation and qualification.

*Summary.*—In a word of summary, therefore, it would appear that stratification originated in the inequalities of deposition, emphasized by intercurrent winds, rains and surface meltings; that the incipient stratification may have been intensified by the ordinary processes of consolidation; that shearing of the strata upon each other still further emphasized the stratification and developed new horizons under favorable conditions; that basal inequalities introduced new planes of stratification, accompanied by earthy debris, and that this process extended itself so far as even to form very minute laminæ.

## Discussion of Causes of Movements of Glaciers.

*Individuality of Ice-layers.*—There is involved in the foregoing conceptions the idea of an ice-layer acting as a unit of movement, or at least individuality of movement in the layer is recognized, an idea that, if correctly entertained, is one of some importance, I think, in the physics of glaciers. This view involves the idea of rigidity rather than viscosity. It will not have escaped attention that the explanation heretofore given of the introduction of earthy material into the ice-layers involves the idea of thrust rather than pull. The picture is not that of gravitation

pulling a thick, stiff liquid down the lee side of an embossment, but of a rigid body thrusting itself over its crest.

It is not easy to escape the influence of these observations if we push inquiry back to the cause of movement. Competency to thrust and measurable ability to individualize itself in layers seem to be requisites. A general force might perhaps so individualize itself, but the phenomena naturally lead us to seek an agency acting within the layers. The limits of this address will not permit me to enter far upon the mooted question of the cause of glacial motion, but the hypothesis that has come to be dominant as the result of the summer's observations may be briefly indicated.

*Granulation.*—Back of the stratification of ice lies the phenomenon of granulation. A glacier starts with snow-crystals or snow-pellets; thence there is a growth into shot-like granules, and thence into larger and larger accretions. Drygalski places the limit at the size of walnuts. So far as macroscopic study goes, this progressive growth of granules constitutes the most essential change through which the ice passes. This invites the inquiry whether the essence of glacial movement does not lie in the changes which the granules undergo. If for a moment we entertain the quite erroneous supposition that all the granules of a given horizon grew from the smallest to the largest dimensions, it would appear that the expansion of the layer and the movement at its free end would be very great. Every doubling of the diameters of the granules would push the foot of the layer forward a distance equal to the whole length of the glacier. The western slope of the Greenlandic ice-field in the northern tract is probably 500 miles. Three or four doublings of the constituent granules would push its foot, if unmelted, over into Alaska; but it is obvious that each original grain does not develop into a larger one—some are sacrificed for the growth of others. The hypothetical case is introduced to emphasize this and to illustrate the possibilities of motion involved in changes of the constituent granules. It would be exceedingly helpful if we knew the laws which determine the destruction of some granules and the growth of others. The process of progressive granulation obviously involves the melting of some particles and the freezing of the water in new relations. The vital question is: At what points do melting and freezing respectively take place and what are the results? We owe to James Thompson the law that pressure lowers the melting point of ice. Whatever incompetency this may have as a sole agency, it may be an extremely efficient factor in determining the precise points at which melting will take place when both heat-energy and differential pressure are present. I suppose the converse of Thompson's law also holds true. We owe to Faraday and Tyndall the observation that ice

melted under pressure promptly freezes again when free from pressure. We owe to the same investigators the law that freezing is facilitated by the presence of frozen surfaces in close juxtaposition. We owe to Tyndall the doctrine that isolated particles or points of ice melt more freely than others from lack of support on either hand. Here, therefore, is a group of agencies which favor melting under certain conditions and freezing under other conditions. Now, all of these conditions affect the individual granule as it occurs in the mass of a glacier. It has its points of contact and pressure, its points of free surface, and its capillary interspaces. It is subject to pressures, torsions and tensions, according to the stresses imposed upon it by neighboring granules. It is always under the influence of gravity acting directly upon it, and also indirectly through surrounding granules. The combined effect is a resultant pressure urging motion down the slope, but with every yielding of the granules, by melting or otherwise, there is a new adjustment of pressures, torsions and tensions, and hence new susceptibilities to melting and freezing. Now these being the conditions of the granules, it seems only necessary that there pass over them an agency capable of acting upon the different susceptibilities of their different parts to produce loss here and gain there, and hence to determine the growth of some parts of each granule and the decadence of other parts. In other words, a granule may continually change its form by partial melting and freezing, by loss in one part and gain in another, and through this may either move itself or permit motion in its neighboring granules, or both.

Now, every warm day sends down into the glacier a wave of heat-energy. This enters the upper surface as sensible temperature, but for the most part it is soon changed to potential heat-energy in the form of melted ice. We should not fail to see that the sheet of melted ice that creeps down between the granules of the glacier as the result of a day's sun-action is as truly a wave of heat-energy as if it remained in the form of sensible temperature. With what freedom the day's heat is conveyed below by the melted product is not accurately known, but there is good evidence that it is large. Upon the Igloodahomyne glacier we observed at midday that the dust-wells were covered with thin films of ice, from which the water below had shrunk away to an average distance of perhaps two inches. The suggestion was that this was the amount of absorption of water which had taken place since the freezing of the film during the preceding night, or, in other words, the absorption of perhaps twelve hours. Circumstances did not permit the careful watching of an individual well, and this inference was not verified, but it is certain that wells of the largest sizes become entirely emptied of their water within a few days after cold weather cuts off their supply. The moisture which,

according to the testimony of all observers, pervades the interior and basal portions of glaciers, has, with little doubt, mainly descended from above.

We seem, therefore, altogether safe in repeating that every warm day sends down into the glacier a wave of heat-energy, sensible or potential, and that every night sends after it a wave of reverse nature. These waves follow each other indefinitely, until by intercurrent agencies they become vanishing quantities. Each season sends through the mass a greater and more complex wave. The problem, therefore, in simplified form, postulates a mass of ice-granules predisposed to melt at certain points and to freeze or to promote freezing at others, acted upon by the ever present but differential force of gravity and swept by successive waves of heat-energy competent to cause melting where predisposition to melting exists and to cause growth by freezing where predisposition to freezing exists. Out of this it would seem that localized freezings and thawings, growths and decadences, innumerable and constantly changing, must result, and with them motion of the granules themselves and of the common mass. This statement lacks very much in completeness and qualification, and I can only ask you to accept it as indicating the line of thought to which the observations of the summer have led.

If the truth lies along this line, it is obvious that these evolutions would proceed with different rapidity in different portions, and that they might affect an individual layer in a degree different from its neighbor layer, or they might affect the common mass to a nearly equal degree, and that therefore differential movements, alike with common movements, would be possible under suitable conditions, and that gravity would control the whole mass much as if it were a liquid.

*Viscosity.**—My observations seem to be adverse to anything which can be properly termed viscous fluency. On two or three of the glaciers it was observed that the surface rises in the direction of the movement of the ice, so that the surface streams flow backward. Possibly this may be explained on the basis of a viscous flowage of the mass, but it seems much more consonant with the view that the ice-mass was pushed forward by its own internal molecular changes, and that it rode up over the inequalities of its bottom as any flexible but relatively rigid sheet would do.

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*The term "viscosity" unfortunately has two senses which are nearly contradictory. Both are derived from the original use of "viscous" to signify a sticky, gelatinous, tenacious, semifluid substance, such as the exudation or extract from the sap of the genus *viscum*. In one case attention is fastened on the pliancy or semifluidity; in the other, on the adhesiveness or tenacity. In the first case viscosity becomes opposed to rigidity and implies an element of fluidity; in the other it only needs to be indefinitely increased to become identical with rigidity, infinite viscosity being perfect rigidity. The term is commonly used in glacial discussions to signify a degree of fluidity, while in physical investigations it more commonly means a degree of tenacity.

The extreme fragility of the ice is difficult to harmonize with the idea of viscosity. It was noticeable that whenever the ice passed over an undulation of even moderate dimensions it was abundantly crevassed. The movement of the ice in most such instances was obviously exceedingly slow, so that the tension brought to bear upon the surface by the small curve was relatively slight and came into action with exceeding slowness. If the property of stretching were possessed in any but the very slightest degree it would seem that crevassing would be avoided. This objection, which was long since forcefully urged by Tyndall, becomes intensified when applied to the broad, slowly moving ice-sheets of the far north.

Lieutenant Peary called my attention to a glacier on the south side of Inglefield gulf which breaks entirely in two in passing a steep descent, and reunites below and moves on. Similar phenomena are well known, but they become more emphatic in this northern region.

I saw no indication that bowlders descend through the ice as heavy substances descend through viscous bodies. As already remarked, the laminæ on approaching a bowlder usually divide and a part curves under and a part curves over it. Nowhere was seen any indication that the bowlders had carried the laminæ down, as the superior specific gravity of the bowlder might be expected to do in a viscous body.

Everywhere the aspect of the ice was that of rigidity rather than viscous fluency. The rigidity, to be sure, did not prevent contortions and foldings of the laminations, such as take place in crystalline rocks, but faulting and vein structures also occur, and there seems no more occasion to assume viscosity in the one case than in the other. Even if a certain measure of viscosity be admitted, it does not follow that viscosity was an essential agency of motion.

There is a theoretic objection to the assumption of viscous flowage in the very fact of crystallization itself. The property of viscous flowage rests upon the relative indifference of a particle as to its special point of adhesion to its neighbor particle. The property of crystallization rests upon the strongest preferences respecting such relationship. Particles of water in their fluent condition lie against and cohere to each other indifferently. When they take on a crystalline form they arrange themselves in specific relationships by the exercise of a force of the highest order. In the presence of this very forceful disposition of the particles to retain fixed relationships to each other, it would seem little less than a contradiction of terms to attribute to them viscous flowage. The crystalline body may readily be made to change its form by the removal of particles from one portion by melting and their attachment at other

points by congelation, but not, I think, by the flowing of crystallized particles over each other while in their crystalline condition.

## Relation of the Glaciers to their Debris.

The northern glaciers afford little that is new respecting lateral and medial moraines, and they may be neglected. It has already been seen that much basal material is carried in the lower layers of the ice. It was also a matter of frequent observation that debris lies under the ice. Apparently the ice sometimes pushes this along and sometimes slides over it. At the end of the glacier the debris within the ice is freed by melting and accumulates as a talus-slope. This sometimes protects the basal layers from melting, and they become at length incorporated in the growing accumulation. Their subsequent melting gives rise to one form of kettle-holes, but only one form. It appeared from the stages presented by the several glaciers that where a glacier is slowly advancing the talus-slope gradually grows forward and constitutes an embankment upon which the glacier advances. It thereby grades up its own pathway in advance. On seeing this process one is at no loss to understand how ice can advance over fields of sand or soil without in any way disrupting them. It buries them before it advances upon them. A large number of the glaciers of the Inglefield region rest upon embankments or pedestals of this kind. Some, which have retreated, have left these exposed to observation. (Figure 13, plate 9.)

Where the frontal material accumulates in a large mass it opposes such a degree of resistance to the ice that its layers are curved upward on the inner slope, and if the glacier subsequently advances the ice rides up over the moraine. Several such instances were observed, but none was seen where the ice showed any competency to push even its own debris, in notable quantity, in front of it. The ice is weaker than the moraine as a whole.

## Wind-drift Border.

Not only is the ice of the north Greenland glaciers weak when tested by the resistance of its own frontal moraine, but it is even weak when compared with the wind-drift accumulations of snow on its front. There is a very notable wind-drift phenomenon connected with the border of the great ice-field of north Greenland to which Lieutenant Peary was the first, I think, to call attention. The winds of the great ice-cap flow chiefly down its slopes, as though by direct control of gravity. They carry great quantities of snow, and this lodges in the lee of the terminal moraine. The border-drift thus formed has a breadth of from 1,000 to

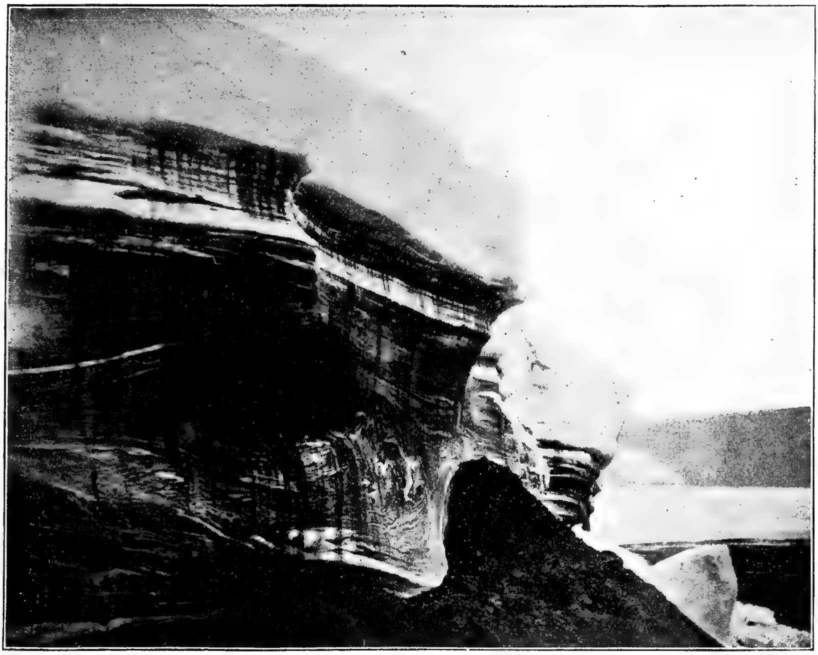


FIGURE 13.—PORTION OF LATERAL FACE OF EAST GLACIER.

Showing the perching of the glacier on its own debris, and the gneiss-like contortion of the laminæ, due to the resistance of the mound of debris in front. The overjutting of certain of the upper layers is also shown. Bowdoin bay seen in the distance.

FIGURE 14.—PORTION OF EDGE OF THE ICE-CAP.

Showing upward curving of basal debris-bearing layers, due to the resistance of accumulations in front.

EAST GLACIER AND EDGE OF ICE-CAP.

3,000 feet, and its slope rises from 100 to 250 feet, though a portion of this elevation is doubtless due to a slope of the earth's surface below. This snow remains from year to year and becomes solidified after the fashion of a glacier; indeed, it is little short of a peripheral ribbon-like glacier, skirting the border of the great ice-cap. Between this and the ice-cap, as a narrow line of division, lies the terminal moraine. The three or four sections across this which were open to observation made it apparent that the moraine was formed by the basal layers of the ice-cap curving upward on encountering the resistance of the wind-drift border in front. The upward movement may have been initiated by a concealed moraine below, but superficially, at least, it would appear that even solidified snow in great mass is sufficient to deflect the advancing layers of ice, paradoxical as this certainly seems.

## Eskers and Kames.

No eskers or kames were seen in process of formation except in miniature type. Nothing of the kind was seen upon the backs of glaciers, because, with trivial exceptions, there was no material there from which to form them. The basal drainage of the glaciers was found to be chiefly accomplished by streams running along the sides of the glacial lobes. The central tunnels which most alpine glaciers possess were generally absent. The lateral streams frequently tunneled under the glacier or were bridged by snow-drifts, and doubtless when the ice has vanished there will be found terraces and side ridges of gravel analogous to one of the forms of eskers of our drift, but nothing distinct or typical was seen. The radical reason lies, I suppose, in the fact that the total drainage is too small and too narrowly confined to the summer months.

So also, in regard to the kames, it was observed that the drainage from the terminal slope of the ice-cap usually followed the inner side of the terminal moraine for greater or less distances until a low spot was found across which it made its way. These transverse channels doubtless afford an illustration of the manner in which the gravel accumulates on the inner side of a moraine during its growth, and is subject all the time to disturbance by the movement of the ice; but here again only illustrative phenomena were seen.

My observations, therefore, seem to have but one important bearing upon our theories as to kames and eskers. The debris of the great ice-sheet is confined to its lower portion, with trivial exceptions. It is almost absolutely wanting in the upper portion and on the surface. The heights at which it is found in the lower portion are not greater than the heights of kames and eskers; therefore, unless we resort to the violent hypothesis

of supposing that the material was borne from lower to higher altitudes by the streams that formed the kames and eskers, only to be let down again, we are compelled to locate their origin at the bottom of the ice-sheet. This appears to confine hypotheses to the question whether accumulation took place in tunnels under the ice or in channels cut back from its edge.

## Drumlins.

No drumlins were seen in process of formation, nor were any seen in the abandoned territory, unless we force interpretation in a few doubtful cases. The observations, however, seem to have some important bearings upon the elucidation of drumlins. The limitation of the debris to the basal layers of the ice limits the horizon of drumlin-making, as in the case of eskers and kames. The observations which showed the weakness of the marginal ice in comparison with the resistance of its own debris furnish ground for comprehending the accumulation of masses of drift beneath the edge of the ice.

In describing the behavior of ice in passing over embossments of rock it may be recalled that the laminæ were found to start on the frontal side of the embossment and to curve gradually upward and backward and at length downward in the lee, the trend of this curve being quite similar to the profile of a drumlin. I suspect that this is the true drumloidal curve, and that it represents the balance or the accommodation between the force of onthrust on the part of the overriding ice on the one side and the friction and resistance of the ice and debris against the emboss-ment on the other. I suspect that the progressive tendency in such a case is toward the accumulation of debris below this drumloidal line, which was apparantly a line of shearing, and that the result of such an accumulation would be a drumlin. Why this particular curve should be assumed is a problem the precise mechanics of which I do not profess to understand, but seeing the curve developed repeatedly I infer that it must be in conformity with the dynamics of ice-motion under these conditions, and that nothing remains requisite to the formation of a drumlin but the lodgment of drift below the drumloidal curve. (Figures 11 and 12, plate 8.)

## Rate of Movement of the Ice.

Lieutenant Peary has commenced a series of observations upon the movements of glaciers of the Inglefield gulf region, both by instruments and by photographs taken at intervals. He found the daily movement of the Bowdoin glacier, the most active in the immediate vicinity of his headquarters, during the month of July to be four-tenths of a foot at the

slowest point, near the east border, and 2.78 feet at the fastest point, near the center, with an average of 1.89 feet for the whole.

The movement of the majority of the glaciers in that region is very much slower; indeed, in most cases it is obviously exceedingly slow. Many of the ordinary signs of movement are absent. In front of the Fan glacier there are cones of granular ice brought down by the surface streams, and also embankments of old snow, soiled, granulated, and half solidified into ice, as though at least a year old, all of which lie banked against the terminal face of the glacier without any indication of movement on its part since their formation. As these lean against the face to heights of 30 or 40 feet at least, it is obvious that there had been no melting of the base of the extremity to counteract the effects of advance. Phenomena of similar import were observed in several other glaciers. The very firm impression was given by such physical signs that the average rate of movement of the glaciers of the region is very slow. At the head of the gulf are a few glaciers which produce large icebergs and which must be notable exceptions to the prevailing slowness of motion.

### Glacial Drift on abandoned Territory.

The amount of drift on the territory once occupied but now free from ice is notable rather for its scantiness than its abundance. On Disco island it was found to be very limited, except along the immediate fronts of the present glaciers. In the Inglefield Gulf region there are at some points very considerable accumulations of drift within a mile or two of the present ice-front, but at the same time much of the territory between the ice-front and the sea bears a very scant covering of drift. No great moraines were seen, nor any thick mantles of drift. The valleys in front of the glaciers are well floored with glacial wash, but even here the rock occasionally appears. Considerable delta-fans project into the gulf, but none of them exceed half a mile in depth.

Consonant with this scantiness of drift, the topography of the borderland shows only moderate evidence of glacial subjugation. It is mildly rounded, but not greatly molded.

### Are the Glaciers advancing or retreating?

Several glaciers on Herbert and Northumberland islands showed evidences of retreat; the terrace-like pedestals which they had formerly built were in part abandoned. Three other glaciers showed by the presence of old moraines immediately in front that in the past they had been more extended than at present. These moraines may be a few hundred years old, but they offered no evidence of very great antiquity. One

glacier was seen overriding its terminal moraine in one portion and retreating within it at another. This, taken in connection with the massiveness of the moraine, probably indicates that it has stood practically stationary for a considerable period.

The most remarkable evidence relative to former extension is furnished by a driftless area on the east side of Bowdoin bay immediately adjoining the present great ice-cap. It is obvious that at this point the ice is as far advanced as it has ever been in the recent geologic history of Greenland. The verity of this driftless area is attested not only by the absence of transported material upon it, but by the exceedingly angular, ragged disintegration of the harder terranes of rock embraced in the complex gneissic series and by the deep disintegration of the gneiss itself. The gullies and ravines reveal the fact that the gneiss is deeply decomposed to a soft, rotten mass, which is not only easily crumbled, but is even pliant under the fingers. It was possible to descend steep slopes by thrusting the heels deep into the softened mass. The combined weight of all this evidence puts beyond serious question the verity of the driftlessness of this region. The area is small, not exceeding three or four miles in maximum diameter, and lies between the ice-edge and Bowdoin bay on ground whose average altitude is less than that of the glacier, so that its immunity from glaciation has not been due to elevation. It is clear, therefore, that the ice-border was stayed at this point by agencies concerned in its own development and not by any topographic barrier.

Immediately at the south of this small driftless area there lies in front of the Gable glacier (which is but a short tongue of the main sheet) a stout old moraine, the surface of which has been notably weathered and has become covered with vegetation in the scant fashion of the region. There is nothing in the nature of this moraine to indicate an antiquity beyond perhaps a few hundred years, but its presence at this point seems to indicate that the ice has stood in the vicinity for a considerable period, and therefore that it is probably, on the average, neither much advancing nor much retreating.

## Former Extent of Glaciation.

It is evident that the occurrence of even a small driftless area on a border of the widest stretch of the Greenland ice-sheet is extremely significant respecting its former extension. The general scantiness of the drift over the territory immediately outside of the present ice seems also to raise doubt as to any great former extension. There are two other lines of important evidence that bear upon this question. Dalrymple island is a mass of hornblendic gneiss rising from the water's edge to a height of perhaps 100 feet, with steep slopes and ragged surfaces. It is

FIGURE 15.—DALRYMPLE ISLAND, NEAR THE GREENLAND COAST.

Showing unglaciated profile.

FIGURE 16.—SOUTHEASTERN CAREY ISLAND.

This island is about thirty miles west-northwest of Dalrymple island. The view shows glacial contour produced by movement from the north; not from adjacent coast of Greenland. The geologic structure of Dalrymple and Carey islands is almost identical, the difference in contours being apparently due wholly to glaciation.

DALRYMPLE AND CAREY ISLANDS.

a famous nesting-place of the eider duck, which finds it suitable to its purpose because of this raggedness of surface. The island bears no sign of glacial abrasion. It stands at the mouth of Wolstenholme sound, on the west coast, in about latitude 76° 50′. In other words, it is just off the border of one of the broadest stretches of Greenland's ice-field. Thirty or forty miles distant to the west-northwest lie the Cary islands, which are formed of almost identical rock. They are very notably abraded by glacial action coming from the north. Striæ are still preserved upon them at heights of 500 feet above the sea. There also occur upon them erratics of limestone, sandstone, shale and quartzite wholly unlike anything that occurs in the islands themselves. So far as I know, no rock of similar kind occurs in Greenland to the eastward. These erratics appear to have come from the region beyond Smiths sound to the north, either from Grinnell land or from the northwestern coast of Greenland—more likely the former than the latter. It appears, therefore, that while a very notable southerly movement from the far north took place down the valley and reached at least to the Cary islands, there was no corresponding movement from the east. (Figures 15 and 16, plate 10.)

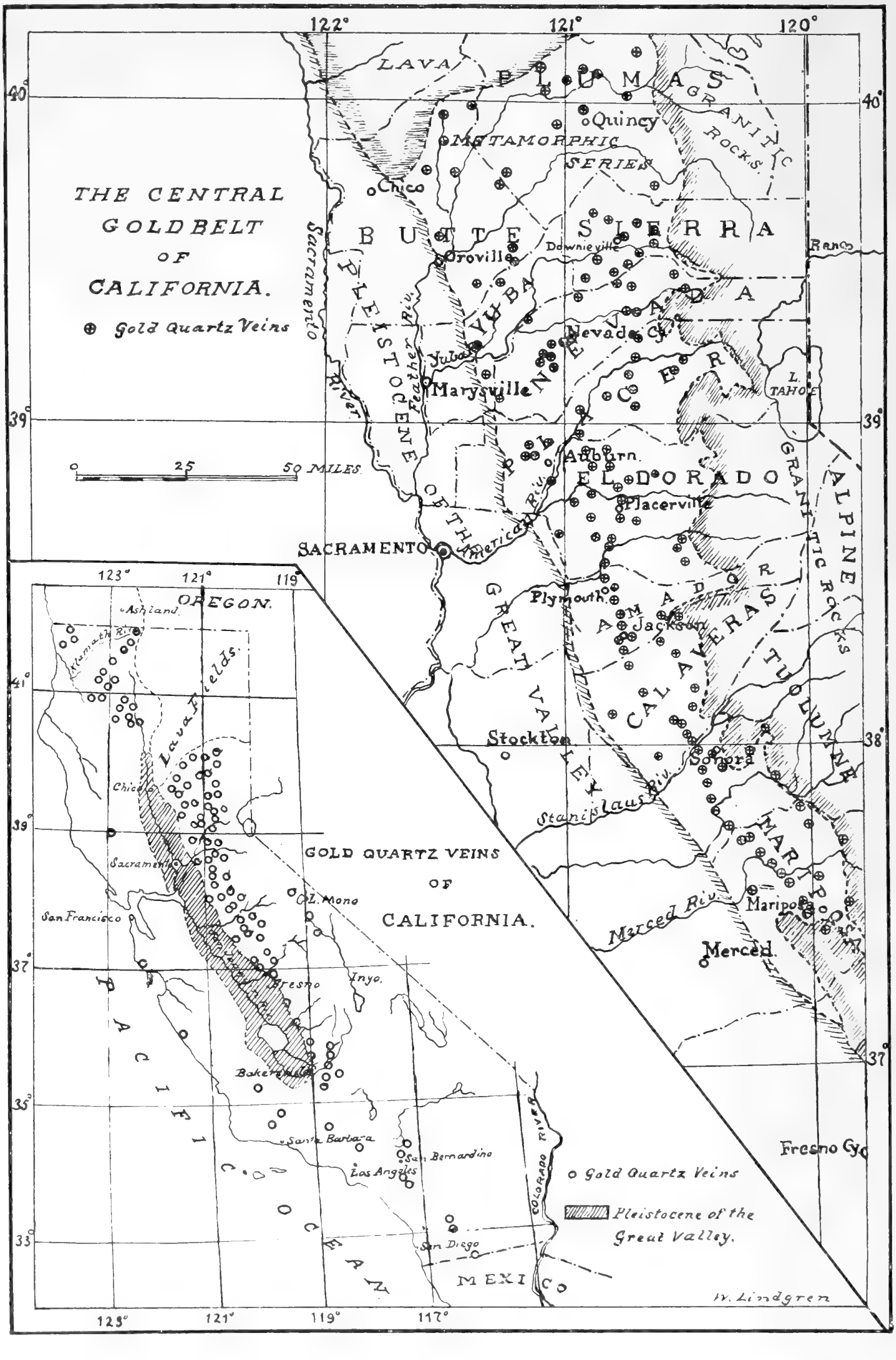
At the very first glimpse of the coastal mountains of southern Greenland I was impressed by their pronounced angularity and the absence, unless it were in the lower valleys, of any notable signs of the horizontal rasping which must have resulted had the inland ice ever pushed across them into Baffins bay. Subsequently I saw approximately a thousand miles of coastline, and an effort was made to discriminate the portions once overridden by ice from those which had not been. Tracts of angular, unsubdued topography were found alternating with tracts of rounded, flowing contours. About one-half of the coast seemed to belong to each type. The inference was drawn that the ice formerly so extended itself as to reach the present coast for about half of its extent, while in the remaining portion the ice fell short.

Combining this topographic evidence with the specific data furnished by a comparison of Dalrymple island with the Cary islands and with the still more stubborn facts offered by the driftless area of Bowdoin bay, the inference seems unavoidable that the ice of Greenland, on its western side, at least, has never advanced very greatly beyond its present border in recent geologic times. This carries with it the dismissal of the hypothesis that the glaciation of our mainland had its source in Greenland.

## Former Altitude of Greenland.

There is no ground to question the former elevation of Greenland. Its plateaus, like its valleys, indicate this; but glacialists are especially concerned to know whether the former elevation of Greenland was coincident

with its glaciation or not. Aside from the contours of the plateaus and valleys, which seem to indicate a fashioning rather by meteoric agencies than by pronounced glaciation, the driftless area appears to afford the most specific ground for induction. Bearing in mind that this is a small area between the present edge of the ice and sealevel, which would be overridden easily and completely by an advance of the ice-edge of less than five miles, it seems necessary to conclude that at the time of the former greater elevation the climatic agencies of glaciation could not have been what they are now, for the increased elevation would have caused an extension sufficient to overwhelm the little driftless area. If it is safe to conclude that elevation favors glaciation, then it is necessary to conclude that during any period of previous glaciation there was here no elevation sufficient to cause an advance, unless accompanied by counteracting adverse climatic conditions. The raggedness of Dalrymple island bears similar testimony. The general angularity of the coastal mountains of south Greenland throw the weight of their evidence in the same direction. It would appear, therefore, that the former elevation of Greenland was not coincident with conditions favoring glaciation.


THE CENTRAL GOLDBELT OF CALIFORNIA.
⊕ Gold Quartz Veins
GOLD QUARTZ VEINS OF CALIFORNIA.
○ Gold Quartz Veins
Pleistocene of the Great Valley.
W. Lindgren
SACRAMENTO
Marysville
Oroville
Chico
Auburn
Placerville
Plymouth
Jackson
Stockton
Sonora
Mariposa
Merced
Quincy
Downieville
Nevada Cy.
Fresno Cy.
PLUMAS
BUTTE
SIERRA
NEVADA
YUBA
PLACER
EL DORADO
AMADOR
CALAVERAS
TUOLUMNE
MARIPOSA
ALPINE
GREAT VALLEY
PLEISTOCENE
LAVA
METAMORPHIC SERIES
GRANITIC ROCKS
L. TAHOE
Sacramento River
Feather Riv.
American Riv.
Stanislaus Riv.
Merced Riv.
50 MILES
OREGON
MEXICO
PACIFIC OCEAN
COLORADO RIVER
Lava Fields
Ashland
Chico
Sacramento
San Francisco
Fresno
Bakersfield
Santa Barbara
Los Angeles
San Bernardino
San Diego
L. Mono
Inyo

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# CHARACTERISTIC FEATURES OF CALIFORNIA GOLD-QUARTZ VEINS*

BY WALDEMAR LINDGREN

(*Read before the Society December 29, 1894*)

CONTENTS



## INTRODUCTION.

The gold-quartz veins of California, in spite of many local variations, form a remarkably well defined type of mineral deposits, the salient characteristics of which it is intended to portray in this paper. The results, indicated in brief outlines, have been obtained during general and detailed mapping for the United States Geological Survey in the gold-bearing region of California.

Referring to the map of the distribution of veins, it should be stated that Inyo county, as well as the central and eastern part of San Bernardino, contains many gold deposits which have not been indicated. In many cases they carry both silver and gold, like the Comstock mines,

* Published by permission of the Director of the U. S. Geological Survey.

or differ in other respects from the normal gold-quartz veins, though the latter are not without representatives. For many notes and valuable suggestions I am under obligation to Messrs G. F. Becker, H. W. Turner and J. S. Diller. The reports of the state mineralogist of California have also been frequently consulted in the preparation of the maps.

## Geographic Distribution.

The general map of California accompanying this paper indicates the extent and distribution of the gold-quartz veins. Beginning in the peninsular range south of the Mexican boundary, the deposits continue in scattered form and with many intermissions up to Fresno county, a few of them also occurring at isolated points along the coast ranges south of San Francisco. In Fresno county they become more abundant, and in Mariposa county the auriferous belt rapidly widens. From here northward to the point where they are covered by the great lava fields of northeastern California the maximum development is obtained. In latitude 40° the gold deposits extend from the great valley on the west to the summits of the Sierra Nevada on the east. In a northwesterly direction the continuation of the gold-bearing area is found in Shasta, Trinity, Siskiyou and Del Norte counties in California, and its northerly end occupies the counties of Jackson, Josephine and Curry in southwestern Oregon. Volcanic flows and more recent superjacent formations cover the gold-bearing area toward the east and north.

A smaller auriferous belt of less importance runs along the eastern slope of the Sierra Nevada, beginning in Alpine county and continuing southward through Mono, Inyo and San Bernardino counties. Most of the deposits along this line differ more or less from the normal type of the western slope.

## Geologic Relations.

In the northern part of the Mexican peninsula and in San Diego county granitic rocks prevail, but in them are imbedded numerous more or less contact-metamorphosed areas of slates and schists of uncertain age. The gold-quartz veins usually occur in, or at least close to, these areas. The principal mining districts in San Diego county are Julian and Banner, in the central part, and Pinacate, near the northern boundary.*

Granitic rocks, with smaller schist areas, continue through San Bernardino and Los Angeles counties. Placer deposits and smaller veins

* Mr W. H. Storms has described interesting lenticular veins from the former locality, which, according to his explanation, doubtless correct, are only modifications of normal fissure veins. Eleventh Ann. Rep. State Mineralogist of California.

are found around San Bernardino mountain, as well as at several places in clay-slate near the summit of the range,* in the central and northern part of Los Angeles county. Very scattered and isolated deposits occur in Ventura, Santa Barbara, San Luis Obispo, Monterey and Santa Cruz counties. In Monterey paying veins have been found near the coast at Los Burros, sandstone being mentioned as the country-rock. A short distance north of Santa Cruz a few gold-quartz veins are said to occur in unaltered sedimentary formations. In Kern county there is a line of paying veins with a northeasterly strike, extending from Kernville to Tehachipi pass. Granitic rocks predominate, but contain a number of smaller schist areas, with which the gold deposits appear to be associated. The locality is of interest on account of the number of hot springs occurring near the veins. Tulare county contains but few quartz-veins, but placer diggings are found along several of the rivers.

In Fresno county, again, several streaks and smaller areas of schists and slates occur in the main granitic mass; again, the quartz-veins, which here attain greater importance, are closely associated with the former, though not exclusively occurring in them. Continuing northward for about fifteen miles to Mariposa, these belts of schists and slates suddenly widen, and at the same time begin to contain numerous and rich quartz veins. Between this region and the lava fields of the north lie the most productive gold-mining regions of California.

The western slope of the Sierra Nevada is from here northward occupied by a gradually widening belt of rocks, to which the name "metamorphic series" is usually given. It attains its maximum width in Butte and Plumas counties and continues across northwestern California and southwestern Oregon to the Pacific ocean. The eastern part and the summit of the Sierra Nevada are still occupied by the continuation of the southern granitic area, bordering upon the "metamorphic series," with an irregular and jagged contact-line, along which evidence of the later origin and intrusive character of the granite may be frequently observed. This contact-line is indicated on the map. The "metamorphic series," sometimes also referred to collectively as the "auriferous slates," is a very complex mass of rocks. It consists largely of more or less altered and highly compressed sediments, of an age ranging from early Paleozoic to late Jurassic, and bearing evidence of having been subjected to several mountain-building disturbances. Associated with these sediments are igneous masses—augite-porphyrite, diabase, serpentine, etcetera—also ranging in age from Paleozoic to late Mesozoic, though the greater mass of them appear to date from late Jurassic or early Cretaceous time. To a considerable extent these igneous rocks have been

* Acton mining district.

acted on by the dynamo-metamorphic processes which also affected the sedimentary rocks, and are largely converted into crystalline schists. It may be said in general that the sedimentary rocks prevail in the eastern part of the metamorphic belt, while along the great valley basic, igneous rocks are found in the greatest abundance. The granitic rocks of the high Sierra Nevada are to a large extent *granodiorites*, the name adopted on the survey maps for a quartz-mica-diorite containing more or less orthoclase. In the metamorphic series there are many smaller masses of the same rock—the latest intrusions—which are usually but little affected by dynamo-metamorphic processes.

The intimate connection of the gold deposits with the metamorphic series or the auriferous slates has been recognized for a long time, and Professor Whitney emphasizes it repeatedly in his works. The auriferous region, indeed, corresponds closely with the extent of the metamorphic series. Even in the south, where the granitic rocks predominate, it has been shown that the gold deposits are usually connected with the scattered schist areas. Few gold-quartz veins are found in the granitic area, and then usually near the contact. Within the typical gold-bearing region the veins are distributed with remarkable impartiality, and occur in almost any of the great variety of rocks which make up the metamorphic series. They are found in granite, diorite, granodiorite, gabbro and serpentine; in quartz-porphyrite, augite or hornblende-porphyrite and diabase; in amphibolite and other dynamo-metamorphosed rocks; in sedimentary, more or less altered slates, sandstones and limestones. In Tertiary volcanic rocks gold deposits are only found on the eastern slope of the range. It is apparently impossible to formulate any law as to their lithologic occurrence or to say that they prevail in any one kind of rock in the metamorphic series.

Regarding the quartz-veins of California F. von Richthofen has made a frequently quoted statement which in a certain sense may be correct, but which unless qualified is apt to lead to grave errors. It is as follows:*

> The auriferous quartz veins "have in their occurrence clearly discernible connection with the extension of the granite. They are crowded closely at its contact with the metamorphic rocks, and occur here partly in the former, partly in the latter. The greater the distance from the granite, the rarer they become in the metamorphic rocks, and only occur as an exception where the influence of the outcropping granite would not be expected on account of its distance. In the same way they become less frequent in the granitic regions as the distance from the contact increases, and are, as a rule, entirely lacking in the interior of the large granite masses."

This statement cannot be accepted for the main granitic contact, which, on the contrary, except near Sonora, is remarkably barren of important

*Zeitschrift der deutschen Geol. Gesell., B. xxi, 1869, p. 727.

deposits. In the larger part of the gold region a wide belt of Paleozoic slates comparatively poor in gold deposits separates this contact from the principal gold-producing districts. In very many places, however, the contact clearly marks the abrupt beginning of auriferous deposits, though perhaps poor and of small extent. The sudden change of recent and Tertiary river-beds from barren to auriferous when cutting across the contact is often very noticeable.

Though not applicable to the main granitic contact, the statement quoted is to a certain degree true of the smaller masses of granodiorite scattered through the metamorphic series, for it is very common to find the gold-quartz veins clustered near their contacts in the manner indicated. It is not so general, however, as to be called a rule or a law, for there are many included granitic masses the contacts of which are in no way remarkable for abundant deposits.

Dr W. Moericke, who has recently published several very interesting papers on the gold deposits of Chile, has come to the conclusion that they are closely associated with acid, igneous rocks, and drawn a comparison between the occurrences of that country and California.* In view of this, it may be well to emphasize the fact that the gold-quartz veins of California do not in their surface relation show any remarkable dependence on acid, igneous rocks. The great mother-lode, for instance, is in location and occurrence of its ores in no way related to such rocks, they being, on the contrary, as a rule, distant from it.

Normal gold-quartz veins in diabase and augite-porphyrite sometimes occur far away from other rocks, although the larger areas of the former are, on the whole, rather barren.

## Age.

Before beginning the discussion of the characteristics of the deposits, their age may be briefly touched upon. It has long been apparent and insisted upon by Whitney, von Richthofen and others that the quartz-veins of California are of late Jurassic or early Cretaceous age, and the same authors have suggested that they probably owe their origin to thermal action following the granitic intrusion. For the larger number of the quartz-veins this is undoubtedly true. It is certain that the majority were formed subsequent to the latest dynamo-metamorphism of the sedimentary and old eruptive rocks of the Sierra Nevada, subsequent also to the granitic intrusion. It is, however, also certain that some deposits antedate this period, for in the latest sedimentary member of the bed-rock series there are conglomerates containing quartz pebbles and free gold,† which appears to have been concentrated as placer gold

* Zeitschrift fur prakt. Geol. Jahrgang, 1894, p. 28.
† W. Lindgren: Am. Jour. Sci., October, 1894.

at the time the conglomerates were formed. It does not appear easy to separate the earlier deposits from the later, but it is probable that they were neither very numerous nor very rich.

Again, the eruptive activity of late Tertiary time which was centered along the summit and on the eastern slope of the Sierra Nevada was followed by another period of thermal activity, and another line of gold deposits was formed. This intermittently recurring action confirms von Richthofen's generalization that a region once metalliferous is always metalliferous. Successive eruptions in such vicinity produce successive mineral deposits, while other eruptive centers are wholly barren of them.

### Differing Types of Gold Deposits.

It is desirable to eliminate a few deposits of a different type from the prevailing one. Most important among them are the *impregnations*,* of which several examples occur in the Sierra Nevada and which may be of two types: First, zones containing grains of iron pyrites disseminated in fresh dynamo-metamorphic amphibolitic schists. These zones are seldom strongly auriferous, but may enrich quartz-veins passing through them, and are apparently similar to the so-called "fahlbands" in crystalline schists. These deposits are distinctly older than the principal quartz-veins and contemporaneous with the dynamo-metamorphism which produced the schists from the diabases and other rocks. Second, impregnations of later date forming irregular zones, in which the massive rocks or schists have been decomposed and filled with secondary auriferous sulphides. These deposits are probably contemporaneous with the principal period of vein-filling and only a phase of it, in which the solutions, instead of following distinct fissures, permeated whole masses of rocks. The first of these types of impregnation is not of great economic importance, but the second sometimes affords large masses of low grade ores.†

### Structural Relations.

Regarding the structural relations of the normal gold-quartz veins it should first be stated that they are fissure veins, and emphatically not so-called segregated ‡ veins or "lenticular masses" in the auriferous slates.

* This word is here used in its general sense, and not confined to the filling of interstitial spaces in porous rocks.

† See later, under "The alteration of the country-rock," page 235, line 4 from bottom.

‡ The term "segregated vein" is not quite clear and has been variously interpreted. A. Phillips evidently considered the only criterion of a segregated vein to be in its parallelism with inclosing slaty or schistose rocks, admitting motion along the walls and filling by foreign material, while R. S. Tarr, in a recently published volume, regards a segregated vein as the result of dynamometamorphism and a concentration of material from surrounding rocks, preëxisting cavities not being necessary. I have used it as meaning more or less lenticular openings in the mass of slates and schists, parallel to strike and dip, produced by longitudinal compression and filled by a sort of lateral secretion or exudation from the surrounding rock.

It is everywhere plain and evident that the fissures have been broken open subsequently to the metamorphism of the rocks. These post-Jurassic and post-granitic quartz-veins form the latest chapter in the Mesozoic revolution in the Sierra Nevada.

Neither Whitney nor von Richthofen commit themselves to an expression of the "segregated" nature of the veins. A. Phillips, in his book on mineral deposits, mentions their affinity to fissure veins, although classing them as "segregated veins." All these writers, however, state that the veins nearly always conform in strike and dip to the inclosing slates. This has evidently led the authors of recent text books to class the California veins as "segregated." Thus Professor J. F. Kemp, in his "Ore deposits of the United States," classes them as such with some doubt, while Professor R. S. Tarr, in his "Economic geology of the United States," thinks that "in spite of the recent observations (by H. W. Fairbanks) it still seems as though these quartz-veins must be of segregation origin."

Quartz-veins like those Professor Tarr has in mind, formed by a sort of dynamo-metamorphic process, I am quite sure do not exist in the gold-belt. The somewhat auriferous "fahlbands" in certain amphibolites approach nearest his conception. I am by no means prepared to deny, however, that there may be some minor ore-bodies deposited in openings in the slate from silicious solutions derived from the immediately surrounding rocks, but if they occur, they are surely exceptions to the general rule. In altered quartzose slates nodules and lenses of quartz seemingly of such origin frequently occur on a small scale.

This rule of "parallelism with inclosing slates" must unquestionably be rejected in a general description of the veins. It should first be pointed out that a very large number of veins, especially in the northern part of the gold-belt, from Placer to Butte county, do not occur in slates or schists, but in massive rocks, such as diabase, granodiorite or gabbro, and among these a predominating direction of dip and strike does not exist. In slates and schists the veins often strike about parallel to the slaty cleavage—that is, northerly or northwesterly—but other directions are nearly as common. Only very exceptionally is there a strict parallelism in both strike and dip. The great mother-lode, for instance, is parallel to the strike of inclosing rocks, but differs not inconsiderably from them in dip. Its character of fissure vein is clear and unquestionable, and has been justly insisted upon by H. W. Fairbanks.* All directions and all dips are in fact represented among the California quartz-veins, only dips below 20° and above 70° are comparatively rare. A general rule for strike and dip cannot be given; different laws guide them in different mining districts. The quartz-veins are the expression

*Tenth Ann. Rep. State Mineralogist of California, 1890, p. 86.

of the greater and minor strains to which the Sierra Nevada has been subjected, and a study of the former will, to a considerable degree, illustrate the latter, which have certainly varied in intensity and direction from point to point. Thus, to pick out a few illustrating examples, the veins of Ophir, Placer county, consist of two principal systems, one set of veins running west-northwest and dipping south, while the other has a west-southwest strike and southerly dip, both cutting the surrounding schists obliquely to their strike and dip. At Grass Valley and Nevada City there is one system with a general northerly direction and dipping either east or west; another system courses east and west and dips north or south at varying angles. The surrounding rocks are here mostly massive. The veins in the vicinity of Sierra Buttes, Sierra county, show the greatest divergencies in strike and dip. Equally variable are the veins about Sonora, Tuolumne county.

The force producing these fissures appears in most cases to have been a compressive stress acting at an angle more or less oblique to the horizontal. In some cases this force produced one large and prominent fracture, but far more commonly one or several series of fractures, or a sheeting* of the country-rock along which the auriferous solutions could circulate. Along the larger fissures considerable movement has taken place, but when the country-rock has been sheeted the motion along the individual joints has probably not been very great. In many cases, when the direction of the movement could be proved, it has been found that a relative upward movement of the hanging wall has taken place. The force did not produce a single, sudden and catastrophic movement; on the contrary, it continued for long time, resulting in repeated dislocations, as proved by the reopening and refilling of some veins and by a sheeting of some veins, producing what is usually described as "ribbon rock." Recemented quartz-breccias are also of common occurrence.

I should here like to mention one misleading circumstance relating to parallelism of vein and country-rock. When larger fissures are opened in massive rocks it is not at all uncommon to find the immediately adjoining wall-rock converted entirely locally into schists parallel to the fissure, under the influence of the enormous shearing stress to which it has been subjected. Such veins would have the appearance of cropping in preëxisting schist-masses, and of parallelism in strike and dip with these. The conclusion to be derived from the relation of the veins to the larger, regionally metamorphosed schist-masses is that the schistose structure antedates the formation of the vein fissures; and that the forces

* The relation of the forces and the sheeting has been discussed by Mr G. F. Becker: Bull. Geol. Soc. Am., vol. 4, p. 13. See G. F. Becker, "Geology of the Comstock Lode," Mon. III, U. S. Geol. Survey, p. 182, and S. F. Emmons, "Structural Relations of Ore Deposits," Trans. Am. Inst. Min. Eng., vol. xvi, p. 814.

to which these fissures are due, while bearing a general similarity to those manifested in the cleavage, often differed from them in direction to a sensible extent.

Different rocks influence the character of the fissures to some extent. In massive rocks they are apt to be straight, clear cut and well defined; in slates and serpentines there is often a tendency to splinter into a network of cracks and fissures, extremely small, but often very rich. In such cases the whole mass, country-rock and vein, may be extracted and milled. Linked veins are common and chambered veins* sometimes occur.

Very long and continuous veins are not common, and in this respect the mother-lode is rather an exception. Only rarely can a quartz-vein be traced more than a few miles, and many important veins crop out only for a short distance.†

## The Filling of the Veins.

The typical gold-quartz veins cannot be considered as anything but fissures and fractures filled with quartz, accompanied by small amounts of native gold and metallic sulphides. Replacement proper of the minerals of the country-rock along the fissure by quartz I have never been able to observe, and cases supposed to be of such nature have always proved to be due to the shattering of the country-rock and the filling of it by silica along narrow cracks. The clean quartz usually forming the vein I cannot account for in any other way than by filling of cavities, as it does not seem possible that a replacement of the ferro-magnesian silicates and other minerals could occur without leaving chloritic stains or other signs in the resulting mass. In all quartz-veins of this type it seems unavoidable to admit the existence of open spaces along the vein, supported at frequent intervals by the contact of the two walls or by rock fragments. Even the heaviest veins show in the underground workings frequent places where the walls "shut down." Such fillings of clean quartz may vary in width from a few inches to several feet. "Horses,"

* G. F. Becker: Quicksilver Deposits of the Pacific Slope, p. 409.

† It is not true that every fissure vein holds out to indefinite depth, though it is probable that most of the larger veins of the gold-belt will continue to a depth exceeding the limit of practicable exploitation. As a rule, the probable permanence of a fissure vein will be in direct proportion to its traceable length and to its width. In regions where strong sheeting of the rocks has taken place it is quite probable that many of the smaller fissures and joint-planes will pinch out and disappear in depth. Fissuring, after all, is most intense near the surface, and probably comparatively few of the fissures reach down to deep seated regions; when the rocks become plastic by pressure and heat, or by a suitable relation between the applied stresses, such as must prevail below a certain level, all fissures must cease to exist. The smaller fissures probably received their quartz-filling by communication with the larger ones, which must be regarded as the principal conduits for the solutions.

of course, frequently appear in the larger veins, separating them in two or more parts. The heaviest veins appear to be found along the mother-lode in Tuolumne and Mariposa counties, where the clean quartz often reaches a width of 10 to 15 feet, and in isolated cases even more. This extreme thickness seldom continues for any great distance. It may probably be safely assumed that gold-quartz veins of this type cannot be formed at any extreme depths below the surface, probably not below 10,000 feet, for at such depth open spaces could hardly exist. These very large fissure veins are, however, not very abundant; a moderate width of one to three feet is far more common. In many cases, indeed, there are no large open spaces at all, but a network of smaller cracks and fractures, in which the solutions deposited their contents.

## Association of Minerals in Gangue and Ores.

In the predominating milky white quartz of the veins but few other gangue minerals are found. Calcite, more rarely magnesium carbonate, or a mixture of both, occur occasionally, but always in subordinate quantities and usually concentrated near the walls. The quartz is ordinarily massive, but excellent examples of comb-structure may be found. Barite * and fluorite are conspicuously absent. A white mica with pearly luster is sometimes found in the quartz at some of the mines along the mother-lode, and a green potassium-mica, colored by chromium, and which Professor Silliman has called *mariposite*,† occurs abundantly in places, though usually not in the quartz itself. Roscoelite, a vanadium-potassium-mica, has been found in one place, and albite occurs in isolated cases.‡ Rhodonite has been found in Plumas county. Titanium minerals, such as titanite, ilmenite and anatase, occur occasionally.

The native gold is distributed through the quartz-gangue in an irregular manner. The particles may be of microscopic size, or coarser, and visible to the naked eye as scales, threads and smaller masses. Occasionally large pieces, of all weights up to fifty pounds or more, will be found. In the ores from the larger mines it is, however, rare to find the gold visible to the naked eye. The gold always contains a little silver, in rarer cases as much as 30 per cent.

A variable but always comparatively small quantity of metallic minerals accompanies the gold. It varies from a fraction of 1 per cent to 5 or 6 per cent, but ordinarily makes up from 2 to 3 per cent of the mass

* For rare occurrences of barite see W. Lindgren, Am. Jour. Sci., vol. xliv, 1892, p. 92, and H. W. Turner, Am. Jour. Sci., vol. xlvii, 1895.

† For analyses see H. W. Turner: "Further notes of the gold ores of California," Am. Jour. Sci., vol. xlvii, 1895.

‡ See the interesting paper by H. W. Turner: Am. Jour. Sci., May, 1894, vol. xlvii, p. 467.

of the quartz. Sulphides are most common, but compounds of arsenic, antimony and tellurium also occur. A list of the associated minerals in the quartz-veins would include the following species:

- Iron-pyrites (universally present).
- Pyrrhotite (not common).
- Copper-pyrites (common).
- Zinkblende (common).
- Galena (common).
- Molybdenite.
- Arsenical pyrites (common).
- Tetrahedrite.
- Antimonal lead sulphides (rare).
- Cinnabar (rare).
- Tellurium minerals—Hessite, Altaite, Calaverite, Sylvanite, Petzite, Melonite (frequent, in small quantities).
- Nickel and cobalt minerals (very rare).*

Marcasite is noticeably absent from gold deposits as noted by Mr Louis. I have once seen it, however, from a mine at Grass Valley.

These metallic minerals, usually referred to as "sulphurets," contain more or less gold and silver and are frequently very rich, the concentrates ranging from thirty to several hundred dollars per ton.

Bismuth and cadmium have been found in small quantities in the concentrates from the Nevada City mines, the former also in Shasta county.† Compounds of tin, wolframium, uranium, boron,‡ phosphorus and fluorine appear to be entirely absent. Cuprite, bornite and chalcocite are also lacking. Cobalt and nickel minerals are occasionally present. Titanium occurs sparingly.

A slight influence of the wall-rock upon the character of the mineral association cannot be denied. It appears to be a fact that veins in granodiorite contain more sulphurets than those in other rocks. Pyrrhotite appears to be entirely confined to veins in this rock. It is known only from the vicinity of Washington, in Nevada county, Sonora, in Tuolumne county, and Westpoint, in Calaveras county. Veins in black sedimentary slate or on the contact between greenstone and slate seldom contain much besides iron-pyrites, and perhaps arsenical pyrites; neither are veins in augite-porphyrite or diabase usually rich in sulphurets. Veins in gabbro often contain copper. These are no strict rules, however, and the influence of the wall-rock may, on the whole, be considered as remarkably small.

## Distribution of the Gold in the Veins.

Gold is universally distributed in the quartz-veins of California. The definition of what is ore, or quartz paying for exploitation and metallurgic treatment, will necessarily vary at different times and in different places.

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* Compare a paper by Henry Louis in Min. Magazine, vol. x, 1893, p. 241, on the minerals associated with gold deposits in general.

† R. Pearce, in Trans. Am. Inst. Min. Eng., vol. xviii, p. 447.

‡ Tourmaline has been found in the abnormal veins of Meadow Lake, Nevada county. Am. Jour. Sci., vol. xlvi, 1893, article 30.

Under exceptional circumstances rock containing as little as one or two dollars of gold to the ton will pay. In the deep mines the tenor of the extracted ore is usually from five to twenty dollars.

In wider veins a small streak near one of the walls will sometimes contain the pay, while the rest is comparatively barren. Equal distribution of value in cross-section is, however, common enough. Considered in projection on the plane of the vein, there is rarely an equal distribution of the gold over large surfaces. The richer ore is concentrated in bodies and masses, which sometimes may be wholly irregular, but which usually show more or less regular outlines. These richer masses are called chutes or chimneys, and appear on the plane of the vein in long-drawn linear or elliptic form, with a dip which usually is above 45 degrees. Flat ore-chutes occur, however, as, for instance, in the Idaho mine, Grass Valley. Their width ranges from a few feet up to several hundred, and their length may exceed 2,000 feet. It is not uncommon to find one of these ore-chutes give out in depth, but another chute will then probably be found in some place below it, if a thorough exploration is carried out. It is a practical rule in many districts, and one which holds good in a remarkable number of cases, that the chutes dip to the left when one is standing on the apex and looking down along the dip. The explanation of the ore-chutes is difficult. They may, as F. Posepny and others have suggested, simply indicate the direction of least resistance for the gold-bearing solutions. This explanation is not entirely satisfactory, for in the intervals between the chutes it is by no means the rule to find the walls shut down tight. On the contrary, it is common to find the barren vein between them as wide if not wider than the rich vein in them. An increase in the quantity of the sulphurets always accompanies the increase of gold in the ore-chutes.

No gradual decrease in the tenor of the ore takes place with increasing depth; on the whole, the character remains constant. Individual ore-chutes may be exhausted, but others, as a rule, are found below them.

Certain veins show no large bodies of milling ore at all, but coarse gold concentrated at certain points; such deposits are called "pocket veins." Small seams may sometimes carry a surprisingly large amount of gold. Intersection of seams or veins often, but by no means always, produce pockets or ore-chutes.

## The Alteration of the Country-rock.

The study of the changes and alterations which the rocks adjoining the fissures have undergone is a subject of the highest importance, for in this way a closer insight into the genetic processes of the vein may often be obtained.

It would at first glance seem more likely that the rock in the vicinity of the quartz-filled veins would have undergone a silicification. Such is not the case. Instead of a silicification there is, as a rule, a most marked carbonatization, or a conversion of the country-rock to carbonates. Most intense next to the vein, the alteration gradually decreases at a distance from it, the width of the altered zone varying according to the width of the vein. The carbonate zone, surrounding the quartz-vein on both sides, may often be studied to great advantage in small veinlets cutting through hand specimens.

This action upon the adjoining country-rock is in itself, to my mind, the strongest possible evidence against the application of lateral secretion in its narrower sense to these veins. It appears to completely refute the theory of the veins being formed by percolating surface waters, and prove the existence of an agency active in the fissures and gradually extending outward.

The solutions circulating in the fissures acted with different intensity on different rocks. Nearly all igneous rocks, acid or basic, are profoundly altered, the latter more than the former, and serpentine more than any other. Only extremely silicious rocks, and especially certain carbonaceous slates, appear to successfully withstand the action of these solutions. The process of carbonatization has not in all cases been carried out to its full extent; in some veins it is more marked than in others; occasionally fresh rock may lie close up to the vein.* Crushing of the rock next to the vein facilitates the process and increases the width of the altered zone, which may vary from a few inches up to twenty feet, and even more in exceptional cases. With all variations, there is no doubt that the process is a general one, and characteristic for the type.†

The result of the process, when it has been thoroughly carried out, is the conversion of the country-rock by replacement to a mixture of carbonates, white potassium-micas (sericite), a small amount of chloritic minerals and residuary quartz; besides, there is always a large amount of iron pyrites,‡ usually more than in the vein; arsenical pyrites‡ is also frequently present, but never, as far as I know, any other sulphides in noticeable amounts. Calcium carbonate usually prevails, but the carbonates of magnesium, iron and manganese are also present. According to numerous analyses, calcium is always added, while nearly all of the sodium is carried away. The potassium of the orthoclase remains transferred to the sericite. As abundant potassic micas are often

*Such cases are perhaps due to layers of impervious clay-like detritus on the wall.

†A good instance has been described by the author in the Fourteenth Ann. Rep. U. S. Geological Survey, in a paper entitled "The Gold-silver Veins of Ophir, California," now in press

‡Both occur as small but extremely sharp crystals, while the sulphurets in the quartz are usually massive.

found in wall-rocks originally very poor in this metal, it is probable that some potassium was also added. In silicious rocks the quartz is often attacked, but never completely carried away. The iron ores and partly also the bisilicates of the original rock appear to have been converted into pyrites,* while the titanium in it was transformed to leucoxene.†

In the case of clean-cut fissures, with well defined quartz-veins, it is usual to find by far the largest amount of gold in the quartz and in the sulphides associated with it. The altered country-rock is not entirely barren, but it does not often contain native gold, and its sulphides are much poorer than those in the quartz.‡ This is not entirely without exceptions, for in several places, usually adjoining rich chutes, the altered country-rock will pay for milling, and may, in isolated cases, go as high as $12 per ton. And again, there are cases in which the altered country-rock is traversed by a great number of minute quartz seams, in which the gold is concentrated. Such a case is the Rawhide mine, Tuolumne county, in which this altered and fissured country-rock is far richer than the main quartz-vein. At the same place the gold sometimes also penetrates and coats the cleavage faces of the adjoining talcose or serpentinoid schistose rock. One frequently hears of native gold in talc, slate or other rocks. I have always found such occurrences to be more or less altered rocks from the immediate vicinity of some vein. The gold occurs on minute, sometimes hardly visible, seams traversing them. Indeed, many fissures are absolutely microscopic.

It has been stated above that serpentine § is peculiarly liable to alteration by the auriferous solutions. The zones of altered rock are in this case often very large and always very characteristic. They may be twenty or thirty feet wide, or in the case of branching veins a whole area, several hundred feet across, may be more or less completely altered. The serpentine is converted into a mixture of magnesic and calcic carbonates, a green micaceous mineral containing potassium and colored by chromium, to which the name of mariposite has been given by Professor Silliman, together with more or less iron pyrites. The altered mass is frequently shattered and traversed by seams of mixed quartz and carbonates. It has a rather coarse, crystalline structure, and a bright green color from the disseminated mariposite. The carbonates referred to as

* A similar alteration has been shown to have taken place in the country-rock of the Comstock lode by G. F. Becker, Monograph III, U. S. Geol. Survey, p. 210.

† The alteration and replacement of the wall-rocks has been emphasized by S. F. Emmons in regard to the fissure-veins of Colorado and Montana, and he points out that, especially where extensive sheeting has taken place, the fillings of open spaces are often small comparéd with the alteration and impregnation of the adjoining country-rock. "Structural relations of ore-deposits," Trans. Am. Inst. Min. Eng., xvi, p. 808.

‡ This fact, as well as many others, of course, speaks strongly against the derivation of the gold in the vein from the decomposed zone adjoining it.

§ As well as talc-schist and other slaty magnesian rocks derived from serpentine.

ankerite by Professor Silliman are in reality, as indicated by H. W. Fairbanks,* a mixture of varying composition, ranging from calcite to magnesite, and often containing considerable iron. Magnesic carbonate, on the whole, predominates. The mineral mariposite is, as Silliman observes, only associated with magnesian and chloritic rocks. Fairbanks † states that it is particularly characteristic of the mother-lode. This is not correct. It is, however, eminently characteristic of all quartz-veins in or at the contact of serpentine, though occasionally occurring in very small quantities in diabase and other basic rocks. The writer has noticed the same characteristic mixture of carbonates and mariposite from a great many places in the gold-belt besides the mother-lode; thus, for instance, at the Phœnix and Red Chief mines in Sierra county, and also near Washington, Nevada county. It appears at the mother-lode wherever that great quartz-vein breaks through serpentine. Quartz mountain, Tuolumne county, is an excellent place to study it.

Along the mother-lode the altered serpentine has been variously interpreted. Whitney inclined to the belief that the vein represented a stratum of silicified dolomite, a theory that has not been supported by more detailed investigation. Fairbanks, who some years ago carefully examined the mother-lode,‡ considered it at first as vein-matter deposited in open fissures, but regarded it subsequently (as the needed, once open space would manifestly have been too large, in places several hundred feet) as an altered, coarsely crystalline basic rock. The latter theory, while nearer the truth, is unnecessary. A careful investigation will not fail to disclose the fact that the mixture of carbonates and mariposite is nothing but an altered serpentine, and abundant transitions may be found to prove this. A locality showing this plainly is the App mine at Quartz mountain, Tuolumne county. This conversion is not astonishing when the facility is considered with which the serpentine is decomposed by carbonated waters into magnesite and chalcedonic quartz. Experiments by C. Doelter § show that while at ordinary temperature and pressure water containing carbon-dioxide will, with simultaneous decomposition and formation of carbonates, dissolve 0.3 per cent orthoclase and 0.5 per cent oligoclase, serpentine will be dissolved at the rate of 1.24 per cent.

The large bodies of decomposed rock referred to on page 226 as containing impregnations of auriferous pyrites and rarely free gold are in many respects interesting. In the ferruginous outcrops the iron-pyrites is usually converted into ferric hydroxide and the gold set free; the whole

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* Tenth Ann. Rep. State Mineralogist, p. 85.

† Loc. cit.

‡ Loc. cit.

§ Allgemine chemische geologie, Leipzig, 1890, p. 190.

mass can then sometimes be profitably mined and milled, though it is of very low grade. Veins and seams of quartz are often entirely absent in these impregnated zones. In the cases which have come under my observation the action on the rock is much the same as in the decomposed wall-rocks of the veins—that is, there is an abundance of carbonates and iron-pyrites in sharp edged, little crystals. While there is abundant evidence of replacement by carbonates, I have not yet seen anything proving a replacement by quartz, though the possibility of such a process cannot be denied. However, in these deposits the action of the solution on the rock-forming minerals must have produced much free silica in solution and probably also much sodic silicate; in fact, there are in these deposits occasional masses of granular, grayish quartz very different from the ordinary vein-quartz and probably partly chalcedonic. This quartz often contains iron-pyrites in small scattered crystals, and appears to represent in part residual masses from leaching, in part deposition from the supersaturated silicious waters. H. W. Fairbanks has recently described two deposits in El Dorado county, the Big Canyon and the Shaw mines,* as showing in marked degree a replacement of the rocks by silica. Though the latter mine was not worked during my examination of the Placerville sheet, I have, through the kindness of Mr H. W. Turner, had occasion to examine an excellent suite of specimens, lately collected. The vein is partly in black slate, partly in a feldspathic dike. Both rocks contain an abundance of stringers and seams of quartz and calcite, but I fail to see any evidence of replacement of the wall-rock by the former mineral. On the contrary, the porphyritic dike is to a very marked degree converted into carbonates in the vicinity of the veins. Regarding the Big Canyon mine, I have seen only two specimens of greenstone impregnated by pyrite from this mine, and collected by Mr H. W. Turner. These specimens show carbonatization to a considerable extent, but no evidence of replacement by silica. It is not intended to deny that such a process may take place, but only to point out that it is something requiring more and more detailed investigation. Calcite is found pseudomorphic after an enormously large number of minerals, while pseudomorphs of quartz after other minerals are much less common.

## Genetic Conclusions.

The country-rock altered to carbonates, standing in strong contrast to the vein filled nearly exclusively by quartz, affords a much-needed key to the genetic processes of the deposits. It shows, first, that besides silica, the water circulating in the fissures contained large amounts of

* Twelfth Ann. Rep. State Mineralogist, 1894, pp. 103 and 114.

carbon-dioxide, as well as dissolved calcic carbonate. It certainly contained sodium as carbonate taken up from the feldspars of the adjoining rocks, probably also as silicate and chloride. It further contained sulphur, in what form is not certain, but most probably as sulphuretted hydrogen or as sulpho-salts. The presence of large quantities of sulphates does not appear probable.

Waters of this composition, containing abundant carbon-dioxide, are only known in nature as ascending, usually hot springs. The process of deposition took place as follows:

At first the carbonated waters began to act with great energy on the soluble minerals in the wall-rocks of the fissures, converting them more or less completely into a mixture of carbonates, potassium-micas and pyrites, adding calcium-carbonate and sulphur, probably also potassium, to them, and abstracting sodium. Finally, this process being completed, and the walls usually coated with crystals of carbonates, the formation of the latter ceased, and in this surrounding of carbonates the silica now began to be deposited, and with it the gold and the rest of the metallic sulphides.

A most interesting question in connection with this subject is, why the walls should, to such a large extent, act as a separating barrier for the gold and most of the sulphides. Mr G. F. Becker, in discussing the quicksilver deposits of the Pacific coast,* has suggested that this may be due to an osmotic action, transmitting through the septum only the chemically active solutions.

Admitting that the gold-quartz veins were deposited by such mineral waters, the next question is, in what form the gold and other metals were in solution. While not intending to enter into a detailed discussion of the difficult problems associated with the question,† I would like to call attention to a few general facts connected with them. Gold is soluble at 200° centigrade in a 10 per cent solution of carbonate of sodium to the extent of 1.23 per cent (Doelter), while silver is hardly attacked. Silicates of alcalies dissolve gold at 250° centigrade to the smaller extent of 0.101 (Doelter and Liversidge). Besides, gold is more or less soluble in a great many other salts (T. Egleston). G. F. Becker has shown the solubility of gold in alkaline sulphides, and the solubility of the sulphides of Hg, Fe, Cu and Zn in either sodic sulphide, sodic sulph-hydrate or sodic carbonate, partly saturated with sulphuretted hydrogen. Silicate of gold, the existence of which was first suggested by G. Bischof, has been frequently mentioned as probably contained in mineral waters;

* Mineral Resources of the United States, 1892, p. 21.

† Mr A. Liversidge has recently given an interesting historic résumé of the experiments regarding the solubility of gold, as well as many original experiments, in the Proc. Roy. Soc., New South Wales, vol. xxvii, 1893, p. 303.

but it should be borne in mind that the existence of this salt has never been proved. It appears that the mentioned facts are sufficient to show that the mineral waters, once circulating in the quartz veins of California, may easily have held gold in solution.* It seems of questionable use to speculate on the particular combination in which the gold is contained in the water, for, according to the views of modern chemistry, watery solutions, when sufficiently diluted, contain the solids in a state of dissociation, so that it is uncertain whether salts of gold could exist as such in the always much diluted natural solutions.

The precipitation of the solids contained in the solution could have been brought about by many means, such as diminution of pressure, dilution, etcetera. The reducing influence of carbonaceous slates, so often maintained as the probable cause of the precipitation of the gold, appears of questionable importance. Veins entirely in massive rocks and far away from any sedimentary areas show too much similarity with those in such areas to attribute a paramount weight to this argument.

### Comparison with Quicksilver Deposits.

There are certain interesting analogies between the gold-quartz veins of the Sierra Nevada and the quicksilver deposits of the Coast ranges. In the Sierra Nevada the association of minerals is native gold with predominating quartzose gangue; carbonates in the wall-rocks; next in importance, iron-pyrites with smaller quantities of the minerals of copper, lead, zinc, arsenic, and antimony; quicksilver-ores are occasionally present. In the Coast ranges we have quicksilver in predominating quartzose, and to some extent carbonate gangue; next in importance,

* These reactions are of course by no means the only ones which are likely to take place. It is thus very likely that the reactions established by C. Newbery (Trans. Roy. Soc. Victoria, vol. ix, p. 754) have taken place. According to him, the iron is contained as ferrous carbonate with sulphates; chloride of gold can be held in such very diluted solutions in presence of alkaline carbonates and excess of $CO_2$. "This is true of chloride of gold, and if the sulphide is required in solution, it is only necessary to charge the solution with an excess of $H_2S$. In this manner both sulphides may be retained in the same solution, depositing gradually with the escape of the carbonic acid." It does not seem probable, however, that sulphates have played a very important part in the chemistry of the gold veins. The explanation of Phillips for the contemporaneous deposition of gold and pyrites (Proc. Roy. Soc. London, vol. xvi, 1868, p. 294) was that as gold is soluble to some extent in ferric sulphate, solution of this salt containing gold was transformed by a reducing agency into pyrites, the gold at the same time being reduced to the metallic state. The presence of a ferric salt in deep-seated waters would be a very unusual occurrence. The presence of ferrous sulphate, on the other hand, in solution carrying gold does not appear possible, for the latter would be immediately precipitated. The fact that in the gold-quartz veins silver occupies such a subordinate position would seem to lend strength to the view that the solutions once circulating in them were not adapted for the dissolving of silver compounds. While thus G. F. Becker found that PbS and $Ag_2S$ were insoluble in sodic sulphide, sodic sulphydrate or in solution of sodic carbonate partly saturated with hydrogen sulphide, these salts or metallic silver may be soluble to a very slight degree when in combination with other compounds. An alloy of much gold with slight amount of silver may thus be soluble. I do not know of any experiments on this subject. Doelter, referring to the dissolving action of sodic silicate and carbonate on silver, remarks that it is "hardly" attacked, thus implying some action.

iron-pyrites with smaller quantities of copper, antimony, arsenic, and nickel; gold is very commonly present.

Regarding the rocks adjoining the deposits, Mr. Becker says* they—

"have in many cases been greatly modified. Metamorphic rocks often appear to have been converted into or replaced by more or less dolomitic carbonates by the action of solutions. . . . Both serpentine and the metamorphic rocks seem to be subject to this conversion."

Containing a similar association of metals, similar gangue and similar altered country-rock, it seems justifiable to express the conviction that similar mineral solutions have circulated in both classes of deposits; and, in fact, the still abundant thermal waters found in intimate connection with the ore deposits in the quicksilver region closely correspond in character to the inferred composition of the once existing hot springs of the gold-belt. They all show free carbonic acid, as well as abundant carbonates (sodic, calcic and magnesic); silica is always present; usually also sulphuretted hydrogen or alkaline sulphides.

Carbonatization of the wall-rocks of fissure veins has neither been described by A. v. Groddeck nor by F. v. Sandberger in their researches, though the former has found abundant sericite in many. The wall-rocks of the Comstock lode, according to Mr. Becker, are rich in iron-pyrites, but do not contain much carbonates. J. H. L. Vogt has shown that along certain veins of Norway the granite and gneiss are altered to products resembling the "greisen" of the tin deposits.

## Origin of the Gold.

Regarding the origin of the hot, auriferous solutions which have produced the gold-quartz veins it is best, at this stage of our knowledge, to speak with great reserve. Even the results of assays or analyses of country-rock must be received with the greatest caution, to make sure that the percentage discovered is primary constituent and not later impregnation. It is not to be denied that many reasons speak strongly against a derivation from the surrounding rocks. Thus, for instance, the diorites of Nevada City and Grass Valley contain an appreciable amount of barium, and still there is no trace of barite in the veins of those localities. In another instance the diabasic rocks of the same region contain copper, and yet the gold veins passing through these rocks are remarkably poor in copper minerals.

In discussing this difficult question there are several broad facts which must be borne in mind:

First, that the gold-quartz veins throughout the state of California are closely connected in extent with the above-described metamorphic series,

* Monograph XIII, U. S. Geol. Survey, p. 392.

and that the large granite areas are almost wholly void of veins, though fissures and fractures are not absent from them.

Second, that in the metamorphic series the gold-quartz veins occur in almost any kind of rock, and that if the country-rock exerts an influence on the contents of the veins, it is, at best, very slight.

Third, that the principal contact of the metamorphic series and the granitic rocks is in no particular way distinguished by rich or frequent deposits.

It is further apparent that gold deposits have been formed at different periods, though by far most abundantly in later Mesozoic times. Some of these later veins may have been locally enriched by passing through earlier impregnations in schist or old concentrations in the sandstones and conglomerates of the metamorphic series, the gold contents of which have, however, only been proved in isolated cases.

These considerations, though involving many most difficult questions, strengthen the belief that the origin of the gold must be sought below the rocks which now make up the surface of the Sierra Nevada, possibly in granitic masses underlying the metamorphic series.*

## Summary.

The auriferous deposits extend through the state of California from north to south in an irregular and broken line.

The gold-quartz veins occur predominantly in the metamorphic series, while the large granitic areas are nearly barren. The contact of the two formations is not distinguished by rich or frequent deposits.

The gold-quartz veins are fissure-veins, largely filled by silica along open spaces, and may dip or strike in any direction.

The gangue is quartz, with a smaller amount of calcite; the ores are native gold and small amounts of metallic sulphides. Adjoining the veins the wall-rock is usually altered to carbonates and potassium-micas by metasomatic processes.

The veins are independent of the character of the country-rock, and have been filled by ascending thermal waters, charged with silica, carbonates and carbon-dioxide.

Most of the veins have been formed subsequent to the regional metamorphism which affected the auriferous slates and the older igneous rocks associated with them, and also subsequent to the granitic intrusions which closed the Mesozoic igneous activity in the Sierra Nevada.

* Mr Becker, reasoning from analogy, has some time ago suggested such a derivation: "Quicksilver Deposits," p. 449. Militating against this view is the general absence of compounds of boron and fluorine so often occurring in ore deposits in granitic rocks.

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# CRYSTALLINE LIMESTONES, OPHICALCITES AND ASSOCIATED SCHISTS OF THE EASTERN ADIRONDACKS*

BY J. F. KEMP

(*Read before the Society, December 28, 1894*)

CONTENTS



## SYNOPSIS OF AUTHOR'S PREVIOUS INVESTIGATIONS.

At the Boston meeting of the Geological Society a year ago the writer presented a sketch of the gabbros which are so plentifully developed in

* The field-work on which this paper is based was done at different times with the support of Professor James Hall, Dr F. J. H. Merrill and the trustees of Columbia College. The detailed reports on the areal geology, with township maps, have been submitted to the two gentlemen first named and permission has been kindly given for this generel use of the materials.

the eastern portion of the Adirondacks. In the introductory part of the paper it was stated that the general geology of this region consisted of (A) a series of quartz-orthoclase (mostly microperthitic) gneisses, which may contain also hornblende or biotite or augite and at times much plagioclase; (B) a series of crystalline limestones often shading into ophicalcites on the east and closely involved with black hornblendic and pyroxenic schists and gneiss, and (C) a great series of intruded plutonic rocks of the gabbro family (anorthosites, gabbro proper, olivine gabbro and norites) which penetrate both the others and are doubtless of later date. The variability of the augitic gneisses in series A was further commented on and the difficulties they present in the way of correlation were emphasized. While likely to be more or less modified in a minor way, the above grouping will probably stand in its essentials.

## Scope of the Paper.

It is the purpose of this paper to outline the characters of the crystalline limestones, ophicalcites and associated schists and to set forth briefly the evidences for believing them to be intermediate in age between the gneisses and the gabbroic rocks. The difficulty of drawing a sharp line between the gneiss and the limestone series arises from the fact that the latter may be a phase of the upper portion of the former, although their petrographic characters are in marked contrast.

## Geographic Distribution of the Rocks.

In general it may be said that the increasing record of observations in the region seems to corroborate that conception of the mountains as a whole which was briefly sketched by Van Hise in the bulletin on the correlation of the Archean and Algonkian, and which was formed during his reconnoissance with Walcott and Pumpelly. This conception involves a central intrusion of igneous rocks with a fringing rim of older gneisses, schists, limestones, etcetera.

It would be nearer the exact truth to regard the intrusions as being in several more or less parallel ranges, with remnants of the others in the valleys between and on the flanks. The anorthosites, for instance, are now known to occur over a northeast-and-southwest distance of about 120 miles (that is, from Keeseville to Little Falls), and over a distance at right angles to this varying from 80 miles as a maximum. In addition to this, H. P. Cushing has discovered north of Keeseville at least one outlier, a description of which he has in course of preparation.

Near mount Marcy the central nucleus is best developed. It consists of a great group of peaks, the highest in the state, which are composed

entirely of anorthosite, but a twelve-mile radius describing a circle from Marcy as a center would cut at least two limestone areas—one northeast and the other southwest—while beyond them, in every direction, both gneisses and limestone occur in abundance broken up into small, elongated areas by outliers of the anorthosites. Thus while the intrusions of these rocks of the gabbro family had perhaps their greatest development near mount Marcy, they really form great northeast-and-southwest ridges, parallel in this respect to the general trend of the Appalachians, and perhaps coincident with one of the earliest developments of this line of upheaval.

## Previous and contemporaneous Work in the Region.

The crystalline limestones and their associated schistose rocks in the eastern Adirondacks have stimulated great interest in those who have studied them since 1822, in which year A. E. Jessup read before the Philadelphia Academy a brief account of his own observations and those made by Dr William Meade in 1810 on lake Champlain.

The limestones are found on all sides of the mountains, as will be shown later in the review of the records, but on account of the general northeasterly trend of the ridges they may be spoken of in a broad way as the east and the west areas. Hitherto attention has been directed chiefly to the east side, because it is the more accessible; but from the west side, although it is a vast tract of wilderness and fringing settlements, no less interesting results will be obtained, and from it we already have most important observations through the work of C. H. Smyth, Jr. The limestones are less disturbed, apparently thicker, and associated with underlying gneisses in areas remote from the Norian intrusions.

Ebenezer Emmons,* in his first work for the New York survey, 1837–1842, was greatly impressed by the limestones of the east side, and the conclusions which he reached regarding their "igneous" character, and in which he was supported by W. W. Mather,† are familiar to all students of geology.

Beginning with field-work under Emmons in 1837, the attention of our honored past-president, James Hall, was likewise attracted to the limestones, and culminated in 1876 in a paper read before the American Association for the Advancement of Science, but never printed, except as a brief abstract. In this paper Professor Hall expressed the belief that they represent a great formation older than the Potsdam and later than the Laurentian.‡

* Report on the Second District, 1842, Primitive Limestone of Essex County, New York, pp. 37, 175, 225, 340. In the last two references he speaks of *primary* limestone.

† Report on the First District, 1843, p. 486.

‡ Buffalo Courier, August 25, 1876; Am. Jour. Sci., October, 1876.

In 1871 T. S. Hunt gave a general review of the mineralogy of these limestones and to some extent of the stratigraphy, and they were called by him Laurentian, but as all the crystalline limestones from southern Pennsylvania to northern Canada are sweepingly included, his conclusions as to stratigraphy are open to criticism.* In 1883 Dr. Hunt † advanced the view that the extended exposures near Port Henry represent a great calcareous veinstone.

C. E. Hall,‡ in 1879, made of those in Essex county one of the four divisions of the Laurentian, and assigns them a later age than the Norian.

G. P. Merrill,§ in 1889, and again in 1890, described the petrography of the ophiolites and traced the serpentine to an original pyroxene.

R. Pumpelly,|| in 1890, before this Society, cited the great lumps of underlying gneiss included in the limestones, and explained them as formed first by secular disintegration, after which they were involved in the deposit of the limestone in and around them upon an encroaching shoreline.

Van Hise, Walcott and Pumpelly,¶ in the same year, made a general reconnoissance of the eastern side of the mountains, upon the study of whose Paleozoic sediments Walcott had been long engaged. Van Hise, with G. H. Williams,** also visited the eastern side and concluded that the limestone rested on gneiss and was penetrated by intrusions of anorthosites.

On the west side, however, the most extended work has been done by C. H. Smyth, Jr.,†† to whom we are already indebted for several papers on the local geology. They are the most important of the contributions made in late years. As previously stated, the crystalline limestone is more extensive and better preserved than on the east, and is also provided with the same serpentinous associate or ophicalcite.‡‡ Professor Smyth leans to the unconformability of the limestone upon the gneiss, although emphasizing the obscure character of the phenomena and the

* Mineralogy of the Laurentian Limestones. Twenty-first Ann. Rep. New York State Cabinet, 1871, p. 47.

† Geology of Port Henry, New York. Canadian Naturalist, 1883, p. 420.

‡ Laurentian Magnetic Iron Ore Deposits in Northern New York. Thirty-second Ann. Rep. New York State Cabinet, 1879, p. 133.

§ Ophiolite of Thurman, Warren County, etc. Am. Jour. Sci., March, 1889, p. 189.

Serpentinous Rocks of Essex County, New York, etc. Proc. U. S. National Museum, vol. xii, 1890, p. 595.

|| Relation of Secular Rock-disintegration to certain Transitional Crystalline Schists. Bull. Geol. Soc. Am., vol. 2, 1890, p. 218.

¶ Bulletin 86, U. S. Geol. Survey, 1892, p. 398.

** Idem.

†† Geological Reconnoissance in the Vicinity of Gouverneur. Trans. New York Acad. Sci., vol. xii, 1893, p. 97. Petrography of Gneisses, etcetera. Idem., p. 203.

‡‡ The name ophicalcite is here used in preference to ophiolite, for the latter is merely a Greek equivalent of serpentine, while ophicalcite means a serpentinous limestone.

difficulty of getting reliable evidence. The area in Gouverneur township and neighborhood on which the above conclusions were based has been since enlarged and studied in greater detail (as shown in Dr Smyth's paper immediately following this), but without altering the earlier conclusions. Smyth has also made some observations on the extension of the Norian in the southwestern border of the Adirondack region,* and, although he does not mention the presence of limestones, Vanuxem † states that an "aggregate of granular carbonate of lime and coccolite . . . and some singular aggregates of a similar kind, with feldspar, having the appearance of a breccia, but evidently the result of accretion," are found in the primary area of Herkimer county.

Emmons ‡ says, "primary limestone appears at intervals throughout Hamilton county accompanied with its usual associate, serpentine;" and Mather § mentions the beds of white limestone in Washington county between Fort Ann and Whitehall.

## The Limestones of the Region.

### *GENERAL DISTRIBUTION.*

With this latter reference we are brought around to the eastern side again, in the region covered by the field-work of this paper. As this especially concerns Essex county, it may be added that the limestones, both of the white and the serpentinous variety, occur in Warren county in notable amounts. There are quarries some eight miles northeast of Thurman station, on the Adirondack railway, which have had a brief period of activity, and various small exposures of the white variety which have been burned more or less for lime. At North creek there is a very considerable thickness well known in connection with the natural bridge near that place, and the same area possibly extends into Essex county at Newcomb.

### *MODE OF OCCURRENCE AND ASSOCIATED ROCKS.*

The limestones and their associated rocks always occur in depressions, so far as my observations have gone, for the resistant ridges are of the harder gneiss or anorthosite. They form geologic sections as extensive as 1,000 feet, in which, however, the limestone strata are much less than half, and in which the true thickness is very difficult to determine because of varying dips, schistosity, the frequent possibility of faults, and the like. There seems to be no question that the limestones are really old calca-

* On Gabbros in the Southwestern Adirondack Region. Am. Jour. Sci., July, 1894, p. 54.
† Report on the Third District, p. 255.
‡ Report on Second District, p. 416.
§ Report on First District, p. 486.

reous sediments, heavily metamorphosed. As to the larger areas, the writer cannot accept Dr Hunt's view that the Port Henry exposure is a veinstone, but of the nature of the accompanying hornblendic and pyroxenic schists it is impossible to feel so certain. They show close analogies with metamorphosed gabbros, and gabbros may even be traced from massive facies into schistose forms, practically identical with them, yet their wide distribution, always along with the limestones, presents an extraordinary invariability on both sides of the mountains. There are also not a few veins whose mineralogy approaches that of the larger limestone areas, but whose long and narrow character in the midst of anorthosite walls indicates that they are undoubtedly vein-fillings.

## The Limestones of Essex County.

### *LOCATION, EXTENT, RELATIONS AND MINERAL CONSTITUENTS.*

In Essex county the limestone areas of largest size are in Crown Point, Ticonderoga and Newcomb townships and are each several square miles in extent. Moriah and Keene townships have also large and well exposed outcrops, and in addition small lenses up to 50 feet thick and a few hundred feet long are not uncommon in Schroon township, associated with black hornblendic schists, which often cover a much greater area than the limestone, and which are so characteristic that we have come to recognize them as an indication of the series.

Split rock, the peculiar little promontory in Essex, is limestone with numerous included knobs and beds of silicates.

In the southwestern part of Chesterfield township ten or twelve miles from Keeseville there is a notable outcrop of the serpentinous variety which has been somewhat quarried.

In southern Jay township there is a good sized ledge, and in Lewis there are not lacking small outcrops.

The accompanying map (see figure 1) makes it evident that these rocks occur over nearly the whole county in small exposures.

Oftentimes, as already stated, the black garnetiferous schists, so abundantly associated with them, alone are seen and serve to indicate their former presence.

The white limestone is coarsely crystalline, usually graphitic, and often set with little scales of phlogopite. It is frequently charged with coccolite or yields specimens practically consisting of this mineral. Seams of quartz are not lacking, and in one or two cases considerable amounts of pure silica have been mined. Rose quartz is characteristically common. The exposures never consist of pure limestone for any extended thickness. In the larger areas great bunches of various sili-

cates appear of exceedingly irregular though chiefly lenticular shape, and small curved and eddy-like inclusions are widespread. They all

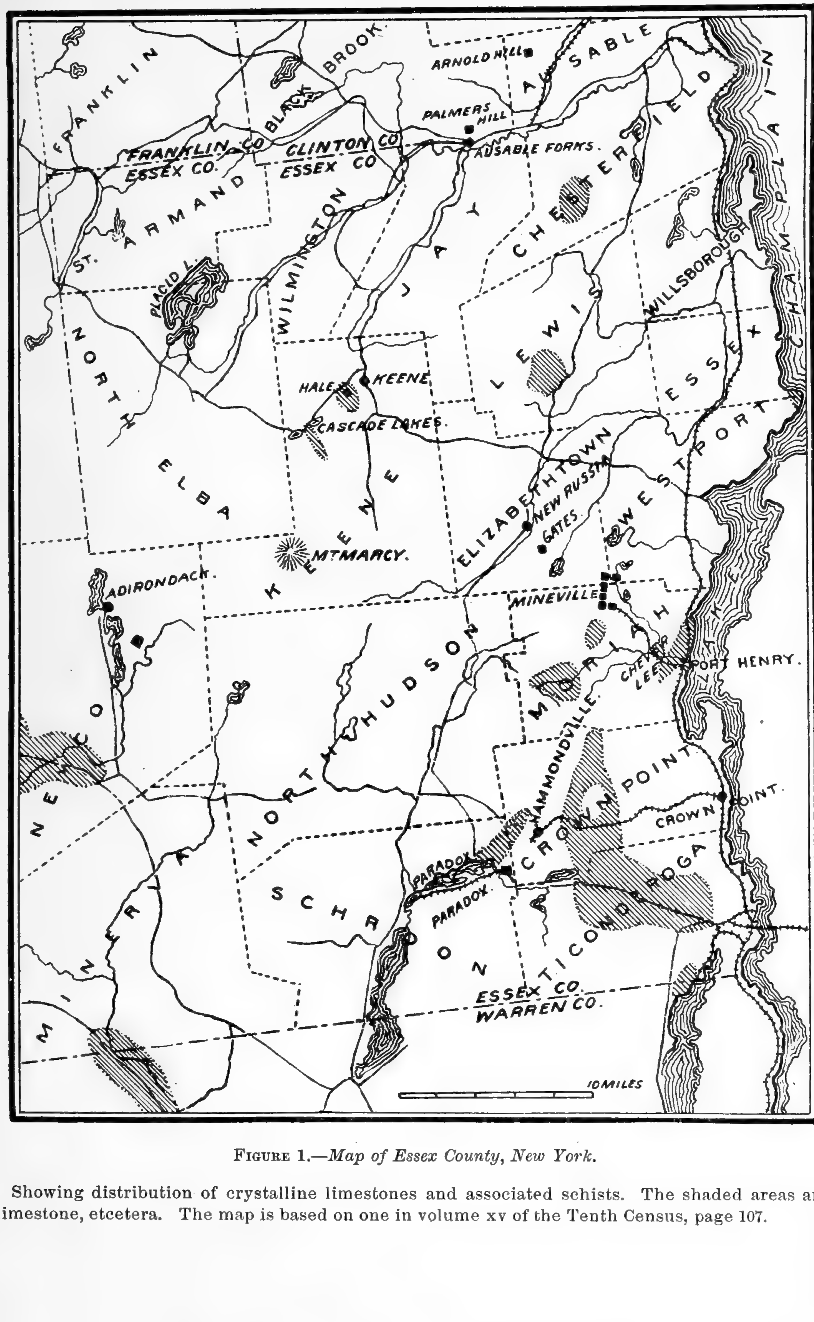


FIGURE 1.—*Map of Essex County, New York.*

Showing distribution of crystalline limestones and associated schists. The shaded areas are limestone, etcetera. The map is based on one in volume xv of the Tenth Census, page 107.

serve to indicate the violent dynamic disturbances through which the limestone series has passed and its capacity of practically flowing under pressure. The extreme irregularity and comparative thinness of the

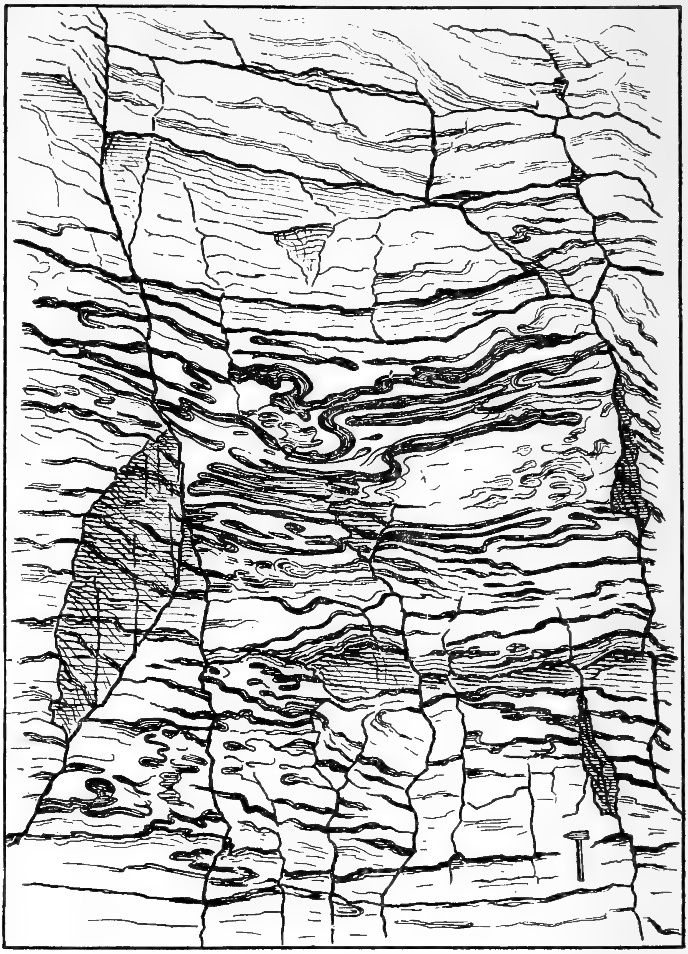

FIGURE 2.—*Group of Inclusions in crystalline Limestone.*

The inclusions consist of feldspar, hornblende, quartz, etcetera. The illustration was traced by Arthur Hollick from a photograph taken just north of Cheever dock, near Port Henry, on Lake Champlain. The height represented is 15 feet.

limestone, together with the abundant inclusions of silicates, indicate that it was originally a very impure deposit, probably with much aluminous and siliceous matter intermingled and with great associated beds

of aluminous and siliceous sediments. The derivation of the serpentine of the ophicalcite from pyroxene illustrates this impure character, and the copious development of the original white pyroxenic mineral is a proof of the presence of silica and magnesia.

With this introduction we may pass to describe in greater detail the two typical exposures in Port Henry and Keene, using them as illustrations of the others. The former is on the edge of the mountains and the latter, which is some 20 or 25 miles to the northwest of it, is well within the great areas of anorthosites.

### *THE PORT HENRY TYPE LOCALITY.*

*General Description.*—The most accessible exposure is near Port Henry, which is in the township of Moriah, Essex county. In size this township is about eight miles north-and-south by nine miles east-and-west. It is chiefly an upland valley, cut off from lake Champlain by a high ridge of gneiss and gabbro running north-and-south, but with a break at Port Henry, through which the valley slopes, down to the water. On the south a high east-and-west ridge of gneiss incloses it, and to the west the great ridges of the Adirondacks begin to appear. Though broken by many minor elevations, the valley character is well preserved. North of Port Henry the limestone series forms the country-rock along the lake for about three miles, being beautifully exposed together with the intruded gabbros in the railway cuts. The series appears on the west side of the eastern bounding ridge of mountains. It is also known in the central portion, south of Mineville, and again in the southwestern part the characteristic coarse white marbles and green ophicalcites are well developed.

The Moriah valley itself is to a very great extent buried under drift, but it is probable that the limestone series underlies nearly all of it, and that the hills of gneiss project, chiefly from faulting and the erosion of the former caps of limestone. The undoubted frequency of faults and the great disturbances this region has undergone make the stratigraphic relations very difficult to determine, but it is evident that the limestone series is limited to the valleys, and that as we reach the higher ridges its characteristic strata fail and are replaced by light colored, rather massive micaceous gneiss, dark basic hornblende-gneiss and intruded sheets of gabbro.

*Cross-sections.*—Figures 3, 4 and 5 represent cross-sections just north of Port Henry. They are one mile each from west to east and have the vertical and horizontal scales the same, and for their topographic outlines are enlarged from the Port Henry sheet of the United States Geo-

logical Survey. All run in a direction of about N. 60° E. and cut the strike nearly at right angles; but as this varies from N. 10° E. to N. 40° W., or even more, the statement is not always strictly true.

Figure 3 represents a cross-section through the large ophicalcite quarry of Mr Treadway, half a mile north of the town, and through a lower lying white limestone, well opened for furnace stock. It shows below this, after a concealed strip, mica-schist, black garnetiferous hornblende-schist, more white limestone and black schist, and finally the great intrusion of gabbro at the lake.

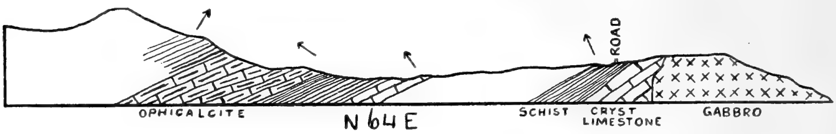


FIGURE 3.—*Cross-section at Ophilcalcite Quarry, near Port Henry, New York.*

The arrows indicate the strike in plan.

The general dip is a flat one of about 20 degrees, as a maximum, to the west. Over the ophicalcite is light gray gneiss, with additional ophicalcite showing higher, but farther south. Still, dips are quite uncertain quantities in these dynamically metamorphosed beds, and are mostly, for individual beds, pressure-effects as shown by sheared inclusions. Where there is a change from one kind of rock to another a contact-dip, however, is developed which is worthy of the geologist's serious consideration. The topography indicates that there is a great fault to

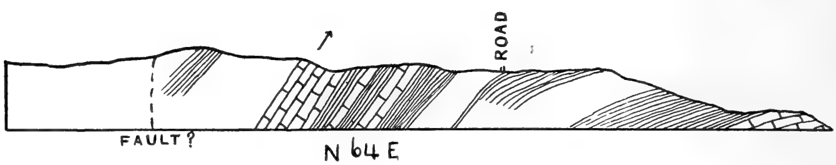


FIGURE 4.—*Cross-section one Mile north of Cross-section represented in Figure* 3.

the west which intervenes between these exposures and the Bald Peak ridge of gneiss and gabbro. The fault is a continuation of the one met in the Cheever mine, as shown in figure 5.

Figure 4 represents a section about a mile north of and parallel with the cross-section indicated by figure 3. It shows much the same succession, except that the limestone appears on the lake-shore instead of gabbro, and at the west end the dips are much steeper. In addition, 300 feet of gneissic rock were cut in exploratory drill-holes with the diamond drill in searching for ore south of the Cheever mine. The rock on the

surface is a gneiss with disseminated magnetite, and some thin beds of ore were met 300 feet below the surface. Exposures are not continuous and the possibility of isoclines is not to be overlooked, but it seems reasonable to think that there are from 1,000 to 2,000 feet of conformable strata in this section.

Figure 5, representing the next cross-section half a mile north, is based on the Cheever mine, and in its underground outline is indebted to Mr B. T. Putnam's map,* omitting a number of small faults, with throws of ten feet and less, which would not show on the scale. There is at the east end an enormous gabbro intrusion which cuts off the lower lying

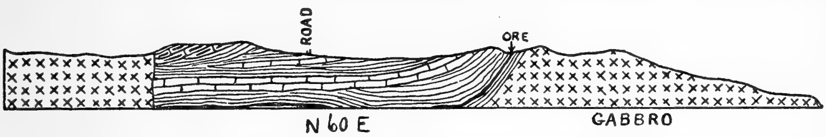


FIGURE 5.—*Cross-section at Cheever Mine.*

limestone indicated in figure 4 and curls up the edges to a high dip. From this they flatten out to the westward, being checked as to their accuracy by the mine-section which is drawn from surveys. Fifty feet below the ore, whose foot-wall is gray pyroxenic gneiss, schistose and then massive gabbro appears, while over it is gray pyroxenic gneiss passing into hornblendic gneiss and crystalline limestone, and finally at the extreme west ophicalcite. A fault was met in the mine which cut off the ore as with a knife and brought the workings against a gabbro wall upon which the ore had slipped down. The topography also indicates


FIGURE 6.—*Cross-section in Moriah Township, east of Sprague's Corners.*

the fault, for the lower hills at the mine are succeeded by a flat meadow where exposures are concealed, but further south a small outcrop is gneissoid gabbro, and fresh normal gabbro was found on the dump of the mine nearest the fault.

From these sections it is clear that white, coarsely crystalline, graphitic, limestone, together with gneissoid and schistose rocks, among which black garnetiferous, hornblendic varieties are most prominent, make up the lower and middle portions of the series, and that the ophicalcite appears toward the top. The sections also show (and the conclusion is corrob-

*See Tenth Census, vol. xv, p. 113.

orated along the lake-shore by the contacts of gabbro and limestone) that the gabbro has been intruded through the limestone. Subsequently great pressure has operated on both, and has made the gabbro strongly gneissoid in places, though leaving unaffected, massive portions, and has wound the limestone around it and detached fragments of it near the contacts.

Figure 6 represents a section in western central Moriah township five miles from the preceding one and on the other side of several ridges of gneiss. The usual black hornblendic schists and limestones appear at the base. The lowest member is a black hornblendic gneiss, which becomes more feldspathic and quartzose in proportion to its remoteness from the limestone. The highest lime-rock found is ophicalcite, as before, but over it (unless there is a repetition from faulting, of which there is evidence) in a succeeding hillock lies hornblendic schist and gneiss, and on the last hill of the section there is a steep fault-scarp and massive gneiss. Below the limestones are massive gneisses also.

The characters common to these sections are important stratigraphically and have a bearing on the origin of the rocks. The black hornblendic schists are quite invariably met all through the region and in the same relations with the limestones. The latter are not thick, but rather in lenticular beds rarely over 50 feet across, but, considered as a whole, of great persistence. They are never pure limestone, but always contain bunches of silicates. The ophicalcites, up to about 50 feet as a maximum, are near the top of the series, but are quite irregular in character and may fail entirely.

*Petrography and Mineralogy*—The Limestone.—The typical limestone is quite pure calcium-carbonate, as indicated by analyses at the Port Henry furnaces. Twinning parallel — $\frac{1}{2}$ R is invariably present, indicating former pressure, as already stated. Almost always scales of graphite are scattered through it, and likewise small tables of phlogopite, irregular quartzes and occasional little prisms of apatite. Disseminated coccolite appears, but outside of the ophicalcite areas it is not common. Aside from this, there is little worthy of note. The bunches of silicates, which vary from small knots through snake-like stringers to great "horses" from 25 to 50 feet thick, are more varied and interesting. In them there has been detected graphite, pyrrhotite, magnetite, fluorite, quartz (usually rose), rutile, apatite, plagioclase, black and brown tourmaline, biotite, phlogopite, muscovite, hornblende, pyroxene, titanite, scapolite, garnet, zircon and wollastonite.

The general mass of a silicate inclusion, as shown by the microscope, is a granitic or dioritic aggregate of plagioclase, quartz and hornblende in rather coarse crystals, usually from 5 to 10 millimeters or more across.

As the extinction angles range upward to thirty degrees, the plagioclase must be a basic one near the anorthite end of the series, and this might be anticipated from the calcareous surroundings; but others which range downward to eleven degrees may belong to labradorite. In such variable bodies a quite extended series is undoubtedly present, and the presence of orthoclase is not to be denied. The hornblende is prevailingly dark brown in color, but the green secondary variety is not lacking, and as there are cases where green pyroxene is clearly passing into it, the green may have been derived from pyroxene in all cases. The pyroxene is a light green augite, and is practically the same one that appears in the gabbro and anorthosites. Pyrrhotite is widespread, and biotite is present in irregular flakes. The other minerals are best developed, if not almost entirely so, in the more pegmatitic portions, or at least in those which are very coarsely crystalline. The matrix of them is most often quartz, or a very hard mixture of it and hornblende. Coarsely crystalline calcite also occurs. Except the titanite, the crystals are seldom well terminated, although the prismatic ones in this zone may be quite perfect and several inches in length.

The evidences of slow yielding to pressure are not rare, for even so brittle a mineral as tourmaline is occasionally bent through thirty degrees or more without breaking. It has adapted itself to the "set" and taken the curved shape. Titanites are of the familiar envelope form, with 2 P most prominent and OP well developed.

Graphite is very generally mingled with these silicates in quite large plates and scales. Near Port Henry a little group of fluorite crystals was found, shading from colorless into yellow. The yellow tint is shown by micro-sections to be due to the development of vermicular bodies like the well known "helminths" of chlorite which occasionally occur in quartz, but which in this case are of extraordinary perfection. They possess the greater interest, as fluorite is usually regarded as a mineral which resists alteration.

While these silicate inclusions in the limestone are at times small and thickly grouped, yet they are found in the quarries of very large size. Individuals 50 feet or more in length and half as much in height are laid bare in several places, and experience shows that no great thickness of limestone is ever devoid of them.

The Ophicalcites.—As already shown by G. P. Merrill, these are variable rocks. At times and for limited stretches they are a homogeneous mingling of small serpentine-pyroxene masses and calcite, but again they have coarse blotchy portions which destroy their homogeneity. The writer's observations corroborate those of Mr Merrill, that the serpentine is in nearly all cases derived from colorless pyroxene, but in several in-

stances the unchanged core of the serpentine has been found to be an isotropic mineral of a high index of refraction. It gave no interference figure, and must therefore be isometric. It is probably a garnet, for spinel is practically the only other isometric mineral which would be likely to occur in these surroundings, and the great resistance of spinel to alteration makes it improbable that it would be the center of a ring of decomposition products, especially when serpentinous or chloritic in character.

The ophicalcite ledges opened in the quarries have many knots or small lenses of silicates, analogous to those in the white limestone, and they yield beautiful crystals when the calcite is dissolved in acid. The best and most interesting are white or slightly pink transparent pyroxenes, an unusual variety, now being investigated by H. Ries. An analysis by Mr Ries yielded the results in column I, and in column II there is given for comparison an analysis of Port Henry material by Mr G. P. Merrill.*

| | I. | II. |
|---|---|---|
| $SiO_2$ | 54.57 | 55.36 |
| $Fe_2O_3$ | .... | 0.22 |
| $FeO$ | 1.62 | 0.57 |
| $Al_2O_3$ | 1.32 | 0.22 |
| $CaO$ | 23.25 | 24.48 |
| $MgO$ | 17.78 | 19.53 |
| $K_2O$ | 0.70 | .... |
| $H_2O$ | 0.32 | .... |
| | 99.56 | 100.38 |

Brown hornblendes, with terminations, light yellow titanite and phlogopite make up the remainder, and the last-named occur in bunches but slightly mixed with other minerals.

The silicate inclusions are drawn out in lenses, according to the pressure to which they have been subjected, and give a coarse flow-structure to the quarry-face.

The hornblendic and other Schists and Gneisses.—These rocks invariably accompany the limestone, and with their dark, rusty outcrops constitute in many respects the most prominent member of the series. The structure is often quite gneissic, being sufficiently coarsely banded to warrant this term. Feldspar laminations may appear and heighten the contrast, but the commoner form is that of a typical coarse hornblende-schist. Under the microscope brown hornblende is seen to be the most abundant mineral. It occurs in large, irregular crystals and smaller

* See Proceedings U. S. National Museum, vol. xii, p. 596.

shreds, the former reaching a centimeter across, and with it are many green augites of much the same size and character. Plagioclase is seldom lacking, and irregular bits of magnetite, shreds of biotite, titanite and apatite appear in decreasing order of abundance. Red garnets, often of large size, are very common, and masses of this mineral from an inch to several inches across attract the observer's attention. They have the usual abundance of inclusions. In several localities, especially in Ticonderoga, scapolite has been found to take the place of feldspar, thus affording the same rock which has been observed by C. H. Smyth, Jr., on the west side at the base of the limestone series.

The graphitic Mica-schists.—At two widely separated points graphitic mica-schist has also been noted. It is a thinly schistose, tender rock, with a peculiar yellow, rusty outcrop, which belies its mineralogy, for there is little of ferruginous minerals in it. It occurs abundantly on the lake-shore just south of Cheever dock and in the interior of Moriah, south of the Pilfershire mine.

Under the microscope the rock is seen to consist chiefly of quartz of all sizes, the largest being 1.5 millimeters in diameter. Plagioclase follows next, but is much less in amount and is frequently microperthitic. Biotite and graphite also appear in irregular shreds. Some microsections show great richness in sillimanite, which forms mats and felts and isolated needles.

Dr F. D. Adams, with whom the writer visited the above localities, states that these schists are common associates of the crystalline limestones in Canada.

The Gneiss.—Assuming that the Cheever mine is in the limestone series, as it appears to be, interesting data are available near the workings. The ore, however, and its containing rocks are so similar to those well within the areas of gneiss at Mineville that hesitation was at first felt about this assumption, but the geologic section left no alternative. Its walls afford massive gneisses. Next the ore, the hanging wall contains plagioclase and an emerald-green pyroxene. A few feet further the minerals are plagioclase, quartz, hornblende, and pyroxene, with a notable microperthitic habit in the plagioclase. Fifty yards away the rock contains microperthite, orthoclase, brown biotite, quartz, which is often included in the feldspar, and almost no plagioclase. Similar gneisses occur in other places above the limestone, and mineralogically they do not differ essentially from others below it. From this evidence and that set forth in connection with figure 6 above, the impression has been strengthened that the limestones will prove to be merely a phase of the great gneissic series A, to which reference has already been made in the introduction.

At a number of localities in Ticonderoga township there is a gneissoid rock, intimately associated with the limestones and schists, containing plagioclase and often scapolite and a curious lavender-colored pyroxene with a pink tinge. Its optical properties are not essentially different from normal pyroxene, but the color is peculiar. This gneiss is abundant just north of Rogers rock, where it is intimately associated with limestone. The same pyroxene is found in silicate bunches in the limestone along with garnet and scapolite.

The abundance of augite in the gneissoid rocks is very striking and of the bisilicates it is the most common and widespread.

It should be further stated that the limestones and schists are penetrated by gabbro intrusions of great size, and that, as shown in figures 3 and 5, intrusive contacts are not lacking. On the lake-shore north of Port Henry they are wonderfully displayed. There is no marked development of contact-minerals in these exposures, but the bunches of silicates are large and appear to be fragments of the gabbro which became involved in the limestone in the great dynamic stresses to which the latter was subjected. At distances from these gabbros dikes much metamorphosed have penetrated the limestones and have even been drawn apart so that the limestone has been forced in between the sundered edges in a way closely simulating igneous intrusions. The quarry near the Pilfershire mine affords a fine illustration of this. The Foote quarry near Port Henry shows a great sheet at its upper crest. In addition to these sheared and metamorphosed dikes, there are frequent exposures of other narrow, unchanged diabasic ones which have come through at a late period in the history of the rocks.

### *THE KEENE TYPE LOCALITY.*

*General Description.*—An area of the limestone series is met about a mile southwest of Keene Center, in the heart of the Adirondacks. It extends, as nearly as one can tell, some three-quarters of a mile along the outcrop, but is of uncertain width, apparently not over 1,000 feet. It appears to be the final termination southward of the belt, which comes up the valley of the Ausable river from the north and is found in detached outcrops in this direction in Jay township. The typical anorthosites of the Adirondacks surround it on all sides, but to the east, in the valley of the river, granite also occurs.

The area is of some exceptional interest because the limestone contains a deposit of iron ore which has proved quite productive in the past. The limestone is thickly charged with pyroxene and graphite, but it is not notably serpentinized.

*Cross-section.*—Figure 7 represents a section paced off in a brook near the largest mine. The strata dip westward toward the main range of hills and away from Keene valley. The black hornblendic schists are not lacking at neighboring exposures, but they do not show in the section which is made up of two bands of limestone separated and bounded by a dense garnetiferous rock.

*Petrography and Mineralogy*—The Granulite.—In thin sections this garnetiferous rock is seen to contain in addition to garnets untwinned feldspar, a little plagioclase, green augite and a little apatite; no other minerals are present. It is thus a granulite and closely analogous to the pyroxene-granulites of Saxony. The association of such rocks with limestones and iron ores in Sweden in similar relations to the above occurrence has been described* by Törnebohm. Despite the general lack of twinning, it would seem as if this untwinned feldspar must be, in part at least, plagioclase. Some twins do occur, but this is not true of

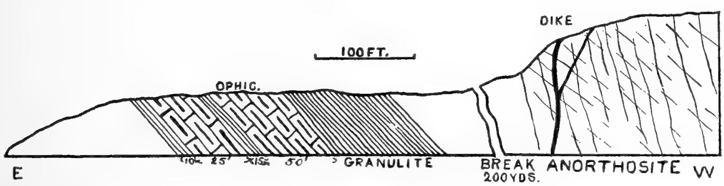


Figure 7.—*Cross-section near Weston Mine, Keene.*

the great majority of the crystals. Of these untwinned crystals the extinction is often parallel to the cleavage, but it may reach 23 degrees. The microperthitic growths are very widespread. One crystal with two good cleavages was detected which gave an axial bar parallel to one of them and was shown by the quartz wedge to be negative. It must be orthoclase. Microchemical tests on another specimen yielded fluosilicates of potash in considerable amount—of soda and of lime rather more. The conclusion is unavoidable that both orthoclase and plagioclase are present, the latter ranging as basic as labradorite. George Hawes† showed years ago that twinning might fail in plagioclase, and especially in the labradorite of anorthosites. As this socalled granulite is regarded as a contact facies of anorthosite, this coincidence is notable. It is quite possible that natron-orthoclases are also present, with microperthitic growths analogous to those which have been found by W. C. Brögger in Norway.

* Neues Jahrbuch, 1874, p. 138.

† G. W. Hawes: On the Determination of Feldspar in thin Sections of Rocks. Proc. U. S. National Museum, 1881, p. 134.

The augite is of a bright green, with a faint pleochroism to yellow. It is often intimately associated with garnet, so much so that the same cracks pass through both minerals and they almost shade into each other. It is pleochroic—yellow $\mathfrak{a}$, green $\mathfrak{b}$ and $\mathfrak{c}$. An optic axis emerges nearly at right angles to the base, and the plane of the optic axes is the plane of symmetry.

The garnet is a good red—fairly intense. It occasionally displays the rhombic dodecahedron, but is mostly irregular. No optical anomalies were noted. A little apatite is the only other mineral in the microsection.

The Limestone.—The limestone bands at Keene are thickly charged with silicates and with magnetite. The former affords a pyroxenic limestone not serpentinized in all cases. The limestone* also contains, in addition to pyroxene, abundant cinnamon-colored garnets of rude crystallographic outlines which may reach an inch and a half in diameter. They are seldom pure garnet, but have green pyroxene mixed all through them. This association of garnet and pyroxene, which is so extremely common all through the region of the Norian rocks, needs chemical investigation. There is probably no great difference in the elements present in the two, and indeed a comparatively slight molecular rearrangement of either—an addition of bases or a loss of silica—would bring about the passage of the bisilicate into the unisilicate.

Some interesting parallel cases have been observed abroad, but as the question is one of mineralogic interest rather than of broad geologic importance, it has not yet been investigated. The crystallographic faces of the garnet are pitted and seamed. There are also granular masses of the same mineral, and the larger garnets contain magnetite and calcite as inclusions.

The ore is a portion of the limestone especially rich in magnetite, and greenish yellow pyroxene almost always accompanies it. Less common specimens are formed of a mass of magnetite and most intimately involved biotite. The ore body proved to be a good sized one at the Hale or Weston mine, the place where the section is taken. The Tenth Census reported that it is an irregular mass in the limestone, which is worked from 200 to 300 feet in depth; that it is from 8 to 16 feet thick, dips at a high angle to the northwest, pitches at forty-five degrees to the northeast, and that it is in white crystalline limestone, much of which was mixed with the ore.

*Selected limestone free from included minerals has been analyzed by H. Ries at the writer's request and the results are as follows: $H_2O$, 2.16; $Fe_2O_3$, $Al_2O_3$, 1.72; $CaO$, 46.79; $MgO$, 5.145; $CO_2$ (calculated for CaO and MgO), 42.42; total, 98.235. The limestone was probably an original siliceous dolomite, the silica and much of the magnesia of which are now segregated in the disseminated pyroxenes. While the writer has had before him the possibility of these ophicalcites being excessively altered gabbros or peridotites, the other view is regarded as more reasonable.

To the eastward, on the adjoining Woods farm, is located the Woods mine, of the same general character as the Hale and also in limestone. The limestone at this opening is likewise contained in the rock previously called granulite, and the true anorthosites are probably not far distant.

The geologic relations of this small area of limestone are interesting and important. It is a pyroxenic limestone, not essentially different from the ophicalcites elsewhere. The presence of garnets in it is, however, exceptional, and their close intermingling with the pyroxene is not seen elsewhere in this rock. In no other instance is there a magnetic ore-body actually in limestone in the Adirondacks and only one other in the contact with this rock, as will be seen later in referring to Cascadeville. In fact the only other case known to the writer in the eastern part of the country is at Franklin Furnace, New Jersey. Rocks much the same as the socalled granulites have in one or two cases been observed elsewhere on the east side of the Adirondacks, but not in association with limestones. A very similar exposure was found in the town of Schroon, where it was an undoubted contact facies of anorthosite on gneiss. It has the same untwinned feldspar and green pyroxene as the Keene rock and creates the same general impression. It has some hypersthene and hornblende intergrown with augite, but lacks garnets. Very similar rocks have been discovered by C. H. Smyth, Jr., on the west side in situations where they seem undoubted contact phases of the anorthosites. In the Keene exposure they are therefore to be regarded as apophyses of the neighboring anorthosite mass and as having been intruded in the limestone. While it is difficult to draw the line in this district between the possible effect of regional metamorphism as a cause of the minerals distributed through the limestone and the contact effects produced on a grand scale by the anorthosites, yet the presence of garnets and magnetite is here exceptional, and it is therefore natural to suppose that the igneous rocks had their influence in bringing them into being.

The shading of a lime-soda rock like anorthosite into one more or less rich in orthoclase, or at least soda-orthoclase, and with abundant microperthitic feldspar affords also difficulties of explanation, but on the whole the geologic relations in the exposures and the parallel cases elsewhere indicate that this explanation is preferable to the one that the granulite represents a gneissic rock interbedded with the limestone.

### *THE CALCITE VEINS.*

The views of T. Sterry Hunt, cited at the outset, suggest that the limestones at Port Henry are a great veinstone or series of veinstones, with the broken fragments of the wall-rock contained in the calcareous mass.

While the writer does not hold these views for the large exposures described above, there are some exposures of a small character that seem clearly referable to this method of origin.

Immediately south of the village of Crown Point is the old eupyrchroite (apatite) locality described by Emmons, where the attempt was made to mine apatite* and where much crystalline granular calcite occurs of a variety very like the true limestone. It is in heavy bedded gneisses, apparently along a fault-line, and cannot be of more than very limited width. The old graphite mines in Ticonderoga township are based on a very long fissure-vein, which cuts the banding of gneisses at right angles and is filled with much pegmatitic matter, as well as with crystalline calcite.

A vein occurs in the anorthosite in northern Willsboro, in the cuts of the Delaware and Hudson railroad.† There is also an included mass of ophicalcites in the anorthosite in the same series of railway cuts. The most interesting vein of all is at Cascadeville, a summer hotel on Edwards ponds or Long pond, as the lake was formerly called (they are now called the Cascade lakes), about five miles west of Keene Center, on the road to North Elba. The lake was originally a continuous, elongated body of water, lying in one of the common faulted passes of the mountains and at the top of a divide. It is a type which, in the report to Professor Hall, the writer has spoken of as "fault-lakes," and which is very wide spread in this region. Such lakes lie between steep cliffs in the passes of the mountains and at the headwaters of a divide. Almost all the passes of this character are provided with them, and in the report above referred to many instances are cited. Long Pond mountain, a precipitous cliff, lies on the north side of the Cascade lakes. An avalanche has come down its face, leaving a narrow gulch and dividing the old lake into the present two. This slide exposed a body of lean iron ore 200 or 300 feet above the water alongside the first cascade. From the ore-body a narrow belt of crystalline calcite, from 8 to 10 feet across, extends from 1,000 to 1,500 feet and more to the south. It is thickly charged with very beautiful coccolite and black garnets. Emmons mentions scapolite also. Two trap-dikes cut the limestone and have served to divert the stream along themselves for a part of its course, they furnishing, as is so frequently the case in the mountains, the easy line of erosion.‡ The walls of the limestone are typical anorthosite.

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* See W. P. Blake: A contribution to the early history of the industry of phosphate of lime in this country. Baltimore meeting Am. Inst. Min. Eng., vol. xxi, p. 157. Blake describes the eupyrchroite as on the contact with a dike of greenstone. There is also a green chloritic rock with abundant and at times handsome brown tourmalines in it.

† T. G. White: Geology of Essex and Willsboro townships, Essex county, New York. Trans. N. Y. Acad. Sci., vol. xiii, p. 218.

‡ Although the writer has visited the locality he is indebted for still more extended observations to Dr N. L. Britton.

No other view of this long, narrow exposure seems reasonable than that it is a vein, although Emmons cites it as a convincing argument for the intrusive nature of limestone.* The limestone as now exposed to observation is much longer and narrower than indicated by Professor Emmons.

## Genetic Considerations.

The problem of the original condition of these rocks, involving as it does the changes through which they have passed and the respective parts played by the local and regional metamorphism, is an obscure one and perhaps in many points beyond solution, but its grander features can be quite well understood.

It is well appreciated by the writer that lithologic similarity, especially in metamorphic regions, is not a form of evidence to be implicitly trusted as to the geologic unity of disconnected and scattered exposures. It cannot be denied that these limestones and schists may belong to horizons quite widely separated and that in a great series of gneisses and schists there may be a number of calcareous horizons, but nevertheless the general presence of these rocks of practically identical character over so wide and closely related an area gives the observer a strong impression of their original continuity, broadly speaking, and in this the writer feels in close accord with the writings of James Hall, in 1876, previously cited. That there is any marked break to be detected between the underlying gneisses and the limestone cannot be asserted. Apparently there is a continuous series of strata especially rich in these rocks at one horizon and perhaps more. Furthermore, although we have usually regarded our gneisses as basal Laurentian it does not appear certain that we have in the Adirondack region, as yet explored, any rocks older than the Grenville series of Canada. The analogy with the Grenville is very close.

The persistence and extent of the limestones and schists give ground for thinking that over this portion of New York there was spread this series of calcareous sediments, and that there were sandstones now represented by the quartzose mica and graphite-schists, and probably also aluminous shales (now represented by the black hornblendic schists), which, however, may be gabbroic intrusions. They rested on the originals of the gneisses which probably involved both mechanical sediments and granite as well as other intrusions. The calcareous deposits were not of great thickness and were sometimes highly magnesian and siliceous, at other times aluminous. Whether they were to some extent metamorphosed before the vast plutonic intrusions of the Norian anorthosites

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* Report on the Second District, p. 39.

and gabbros is beyond determination, but certain it is that these latter were forced through calcareous deposits rending them asunder and embracing small areas of them in the plutonic rocks. At a distance from the anorthosites the series exhibits but slight disturbance. On the west the limestones rest on the gneisses in such a way that, as shown by C. H. Smyth, Jr., they can be stratigraphically quite well worked out, but in the east and in the central portion the intrusions have been so extensive and the disturbance so enormous that the true succession is difficult to decipher stratum by stratum.

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# CRYSTALLINE LIMESTONES AND ASSOCIATED ROCKS OF THE NORTHWESTERN ADIRONDACK REGION

BY C. H. SMYTH, JR.

(*Read before the Society December 28, 1894*)

CONTENTS

## Introduction.

Since the publication of the report of Emmons on the geology of the second district of New York, the northern and western portions of the Adirondack region have received little more than casual mention in geologic literature. This is even more markedly true than in the case of the eastern counties, though little enough has been done there until quite recently.

Having spent some time in the contiguous portions of Saint Lawrence, Jefferson and Lewis counties, the writer has ascertained certain facts which may be taken as a starting point for an inquiry into the geologic relations of the region. Although but little more than a beginning has been made, it seems expedient to present some of these facts with the conclusions drawn from them, particularly to establish a basis of comparison between the phenomena exhibited in different portions of the Adirondack region. With this end in view it is proposed to give a condensed description of the limestones themselves, with a more detailed account of those other crystalline rocks of the region whose character and relations to the limestones are pretty clearly established.

## Extent and Character of the Limestones.

There is a marked contrast in the extent of the limestones between the region described by Professor Kemp in the preceding paper and that now under consideration. In Essex county they form rather limited patches, while in Saint Lawrence, Jefferson and Lewis counties they constitute extended belts many square miles in area. For instance, a limestone belt begins near the village of Antwerp, and extends eastward across the township of that name, across Rossie and Gouverneur, into Hermon. This belt has been traced more than twenty miles along the strike, while the average width is perhaps six miles. A narrower belt extends across Fowler into Edwards township, and is distinguished by containing extensive talc deposits. Farther to the south, a third belt of limestone, that appears from beneath superficial deposits which probably hide an extension westward, begins just west of the village of Natural Bridge, Jefferson county. This belt crosses the townships of Diana, Lewis county, and Pitcairn, Saint Lawrence county, with an average width of two or three miles, narrowing toward the east and passing into Edwards. No extended belt is known farther south, though this may be due to the fact that in this direction there is a dense and unfrequented forest; but scattered patches of limestone have been noted in various portions of

Herkimer and Hamilton counties. Similar patches occur in the region under consideration, in addition to the extensive belts.

The limestone in all of these belts is highly crystalline, rather coarse, and usually light gray or white, though darker gray portions occur. Of the disseminated minerals phlogopite, graphite, pyroxene and tremolite are most common. They may be evenly distributed or segregated in lumps, the tendency toward the latter mode of occurrence being less marked than in the eastern section.

In general the limestone is very massive, so that it is difficult to ascertain the strike and dip with any degree of accuracy. When observable, the former is generally northeast, the latter northwest, though exceptions to the rule are common.

Intimately associated with the limestones are several varieties of gneiss, which may be roughly divided into garnetiferous and micaceous on the one hand and pyroxenic and hornblendic on the other. Of the former group some are distinctly interbedded with the limestones, while others are of doubtful relation. Among the pyroxenic and hornblendic rocks many have the appearance of interbedded members, but others, both in composition and in structure, closely resemble somewhat modified intrusions.

Wherever these hornblende and pyroxene rocks appear they show a great amount of crumpling and crushing. This ranges from slight plication to most elaborate contortion, followed by crushing of the rock until, in extreme cases, it is reduced to a mass of angular fragments held together by a paste of limestone. In this way remarkable breccias are produced, whose origin might be obscure but for the fact that every step in the process of their formation is shown. In all such cases the limestone displays little or no sign of structural change, having the appearance of a plastic mass in which the contained layers could be twisted to any extent. It must be noted, however, that a large amount of crushing and distortion in the limestone might be completely obscured by subsequent recrystallization. These facts make it apparent that when the limestone is free from gneissic layers it may present a massive and undisturbed appearance, and yet have been subjected to intense mechanical strains.

This is a matter of importance in considering the question of the metamorphism of the series, for while the character of the limestone as a whole might be thought to point to an absence of any considerable mechanical disturbances, the phenomena of the crushed gneiss show that, as a matter of fact, the series has been subjected to intense pressure. The plastic nature of the limestone must also be taken into account in all efforts to work out the structure of the series, as it is liable to introduce complications which may be the cause of much inaccuracy.

The marked resemblance of the limestone series to the Grenville series of Canada has been noted by Van Hise,* with the suggestion that they are equivalent. The difficulty of establishing such equivalency leads the writer to prefer a local designation for these rocks, and he has elsewhere † suggested the term Oswegatchie series.

### Gneissic Areas.

The areas intervening between the belts of limestone are occupied by gneisses whose origin and relation to the limestone series constitute one of the most important problems presented by this region. In many cases the portions of these gneisses immediately adjacent to the limestone closely resemble the interbedded garnetiferous gneisses and doubtless should be regarded as members of the limestone series. These varieties usually pass somewhat gradually into more massive gneisses of plutonic aspect, and cases are not few where the latter are in direct contact with the limestones. It is difficult to resist the impression that these massive gneisses are, at least in part, of igneous origin, and that this is sometimes the case will be shown below, but whether or not it may be accepted as a general explanation it is impossible to say at present. To the writer it seems probable that absolute proof as to the origin of many portions of the gneiss will never be found.

### Igneous Rocks.

The rocks of undoubted igneous origin may be classed, with few exceptions, as granite, diorite, gabbro and diabase. Of these the first two have been in part described by the writer in another paper,‡ so that a brief summary of the facts then stated will suffice.

### Granite and Diorite.

A more or less interrupted ridge of granite extends across the townships of Antwerp, Rossie and Gouverneur, and has not been traced to a limit on the east. Besides this, there are numerous isolated masses scattered irregularly about. It is a biotite-granite or granitite, whose intrusive nature is shown at many points where it breaks through the limestone. The structure of these contacts admits of no doubt of their character, but metamorphism, while not absent, is hardly as extensive as might be expected. Diorite appears as a basic phase of this granite, with a

* Bull. 86, U. S. Geological Survey, p. 508.
† Report to State Geologist of New York (unpublished).
‡ Trans. New York Acad. Sci., vol. xii, p. 203.

gradual passage from one to the other perfectly exhibited. This area of the granite with associated diorite is clearly defined, being surrounded by the older limestone, with the relations between the two perfectly distinct. Except at a few points, there could hardly be any confusion between it and the gneisses of doubtful origin, although the granite is itself sometimes prominently gneissoid.

A more complicated case is presented by a series of granitic rocks extending along the northern boundary of the limestone belt of the townships of Diana and Pitcairn. In this instance the granites are quite variable in character, ranging from a rather fine grained to a coarse porphyritic variety, containing feldspar phenocrysts an inch or more in length. At the same time the color varies, showing white, gray and red.

The microscope shows much variation in the feldspar of the rocks, as plagioclase quite often preponderates over orthoclase. The amount of quartz is also variable, but the dark mineral is quite constantly biotite. These variations suggest that the rocks can hardly belong to a single intrusion; but for present purposes they may be classed together under the head of granite.

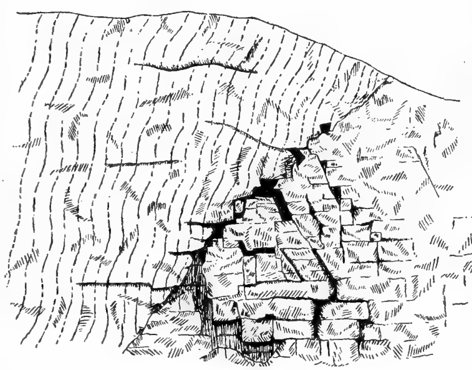


FIGURE 1.—*Granite Cutting laminated Gneiss.*
The drawing is from photograph taken half a mile north of Harrisville.

Only one good contact with limestone has been found along this belt, but this shows abundant evidence of intrusion, with decided contact metamorphism, resulting in the formation of a zone composed of pyroxene, scapolite, titanite and garnet.

The igneous nature of the granite is not, however, dependent upon this single locality for its proof. On the contrary, there is a high cliff extending two-thirds across Pitcairn township, which contains most abundant evidence of the intrusive nature of the rock. This cliff is made up of finely laminated gneiss, such as occurs interbedded with the limestone (and which is therefore regarded as a member of the limestone series), cut through and through by granite. At some points the granite sends many tongues and veins into the gneiss, while at others the gneiss is wholly cut out by the intrusion. As a result, the cliff at some places consists entirely of gneiss, at others of a mixture of gneiss and granite, and at still others of granite alone (see figure 1). Wherever the granite

is in small tongues or veins there is a marked tendency for them to follow the lamination of the gneiss, producing structures precisely like those described and figured by Lehmann* in the case of similar intrusions occurring in Saxony (see figure 2). At many of the exposures abundant inclusions of gneiss in granite give further evidence of intrusion.

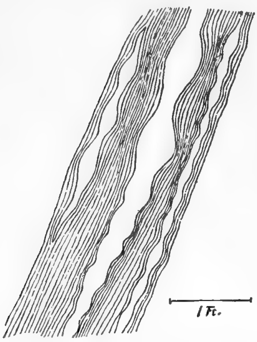



FIGURE 2.—*Granite Veins parallel to Lamination of Gneiss.*

The drawing is from field sketch made one mile north of Pitcairn Forks.

While these relations are most extensively shown in Pitcairn, indications of the same sort may be found in Diana, particularly just north of Harrisville, north of Indian lake, and two miles east of Natural Bridge, on the Bonaparte road.

Thus it is evident that the limestone belts of Antwerp-Gouverneur and of Diana-Pitcairn are separated by a gneissic area whose southern border is made up largely of intrusive rocks. How much of this area is but a continuation of the intrusions can be determined only by very close and careful study, and perhaps not even then; but the facts at hand are certainly suggestive and seem to point out a fruitful line of inquiry.

## GABBROS.

### *FIRST VARIETY.*

*Area of Occurrence.*—Of gabbros there are three varieties, the most important being of somewhat exceptional character, which renders its affinities rather uncertain. The most typical gabbro occupies an area of hardly more than a square mile, just east of the village of Pitcairn, or, as it is called more commonly by the inhabitants, Geers. The southern edge of this area is marked by a steep cliff, like that formed by the granite and gneiss just described. The two cliffs are almost in line, though not continuous, and the structural relations of both are very

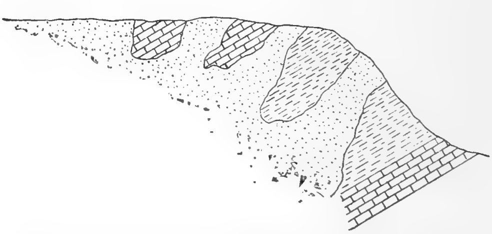


FIGURE 3.—*Basic Gabbro cutting Limestone and Gneiss.*

Diagramatic section of exposure at Pitcairn.

*J. Lehmann: Untersuchungen über die Entstehung der Altkrystallinischen schiefer Gesteine, p. 20.

similar. On the other sides the gabbro area falls off more gradually. The section at the cliff shows at the base limestone dipping under the next higher member, laminated gneiss. Above this again there is limestone, largely cut out by gabbro, which also intersects the gneiss (see figure 3.) The structural relations are perfectly clear and admit no doubt of the intrusive nature of the gabbro, which is further shown by a conspicuous amount of contact metamorphism.

*Macroscopic Characteristics.*—The most pronounced feature of the gabbro as seen in the field is the great variation from point to point in composition and structure. On the one hand the constituents may be less than a millimeter in diameter, while on the other they may reach an inch or more in their greatest dimension. Naturally, the finer portions are more conspicuous near the margin, but there are abundant exceptions to this rule. In composition there is a range from a nearly black rock, composed almost wholly of ferro-magnesian minerals, to a rock consisting chiefly of white feldspar, with a few prismatic pyroxenes. The latter is the least abundant variety, the bulk of the rock being rather dark-colored. It is surprising how many varieties of the gabbro may appear in a small area, the passage between the most extreme phases often taking place within five or six feet. Such variations are, of course, very common in basic igneous rocks, but it is probable that there is nowhere a more striking example of the phenomenon.

*Mineralogic Composition and Characteristics.*—The microscope shows the rock to consist of plagioclase feldspar, pale green augite, hornblende, apatite, pyrite and alteration products. All of the minerals, save the apatite, are allotriomorphic, though in the feldspathic variety the augite has an imperfect prismatic habit. The augite is normally the prevailing ferro-magnesian constituent, though it may be replaced by hornblende. The relation between the two is interesting, for if it is ever safe in the absence of idiomorphic boundaries to say that massive hornblende is derived from pyroxene, it may be stated in this case. Every stage of the process is clearly shown, beginning with the appearance of small spots of deeper color scattered through the light green of the pyroxene and ending with a complete substitution of hornblende. The change does not begin in any particular portion of the pyroxene, but at numerous points scattered through the mass. Professor Iddings * has pointed out the need of caution in accepting such an explanation of the origin of hornblende, but in the present instance the facts are very strong in its support.

The extinction angles of the feldspar indicate the prevalence of an acid

* Twelfth Ann. Rep. U. S. Geol. Surv., p. 610.

labradorite, but in portions of the rock having an abnormally small amount of ferro-magnesian minerals and containing some quartz there is a much more acid plagioclase and probably some orthoclase. The feldspar of all specimens is entirely free from the fine inclusions so common in the feldspar of most gabbros.

The feldspar is often much altered to kaolin and to muscovite, more rarely, to scapolite. This latter change is interesting, recalling the group of scapolite-diorites and "gefleckter gabbros." It is also suggestive in connection with the scapolite rock of Gouverneur previously described by the writer.* A peculiar feature of the gabbro, considering its rather basic character, is the almost complete absence of magnetite and ilmenite, these minerals being rarely seen in microsections.

*Effect of Contact.*—The contact phenomena are important only where the gabbro cuts the limestone, as it has little or no effect upon the gneiss. The limestone is converted into a coccolitic mass, chiefly green pyroxene, but containing considerable quantities of garnet, scapolite and sphene, the latter often in perfect, though very small, crystals, the other minerals being in grains. This change is shown both on the border of the mass and in inclusions, some of which are changed throughout to the aggregate described.

*Relation of the Gabbro to Granite Intrusions.*—As the gabbro occurs in the line of granite intrusions above described, the relation between the rocks is a matter of interest. If the acid granites of Gouverneur pass into quartz-free diorites it might be thought that the gabbro is a basic phase of these more basic granites. That this is not the case is conclusively proved by a contact between the gabbro and the granite. The contact is sharp, with no transition, and clearly irruptive. The structure of the contact does not, however, prove the relative age of the intrusions, but the extreme fineness of the gabbro and its exceptional aspect under the microscope indicate that it is the later of the two rocks.

*The Gabbro as a Basis of Comparison.*—This gabbro is of particular interest in affording a basis of comparison for rocks from other portions of the region, where the field relations are less clear. The black gneiss from southern Hamilton county, recently described by the writer,† affords an instance. This rock was referred to as probably belonging to the gabbro series, although no positive proof of this was at hand. While not, of course, affording such proof, the Pitcairn gabbro gives great support to the supposition named, as there is a strikingly close resemblance between many portions of the rocks, though the Hamilton county rock

* Trans. New York Acad. Sci., vol. xii, p. 215.

† On Gabbros in the southwestern Adirondack region. Am Jour. Sci., vol. xlviii, p. 54.

has certain features connecting it more closely with the pyroxene-granulites.

### SECOND VARIETY OF GABBRO.

*Area of Occurrence.*—A second variety of gabbro occurs on both sides of the road about midway between Oswegatchie Settlement and Diana Center. The field relations of the rock are not so clear as in the case just described, but they indicate an intrusion of no very great extent, cutting the third variety of gabbro, to be considered below.

*Description of the Rock.*—The rock may be sufficiently described by the statement that both in the hand specimens and in microsections it is practically identical with the hypersthene-gabbro of southern Hamilton county described in the paper referred to above.

*Relations and Origin.*—As the two localities are about 60 miles apart, it would seem at first sight rather strange that there should be such identity in the character of the rocks, which occur in quite inconspicuous masses. The explanation of the fact doubtless lies in the suggestion made in the paper cited, namely, that these small bodies of fine grained gabbro have an intimate connection with the great gabbro intrusions of the region. They are products of the differentiation of the magma, which was the source of these wide spread intrusions, and are alike because derived from the common source. The region is regarded as a petrographic province in which the igneous rocks bear most intimate genetic relationships to each other; and many facts indicate that this is the case. If this supposition be correct, it is to be expected that the fine gabbros may be found anywhere in the vicinity of the large intrusions.

### THIRD VARIETY OF GABBRO.

*Chief Characteristic.*—These great intrusions seem to be represented in the region under consideration by a rock of so much interest in its relation to the limestones and gneisses as to merit rather extended consideration. It is the third variety of gabbro previously referred to, and, as there stated, is of somewhat unusual character. This fact appears in the variable nature of the feldspar, ranging from highly twinned plagioclase to a finely fibrous microperthite, while there is a corresponding change in chemical composition. Thus, different specimens of the rock require, from a strictly petrographic point of view, different names, ranging from gabbro and anorthosite to augite-syenite, but it will for present purposes be considered as a whole under the term gabbro, its geologic relationships rather than its petrographic affinities being the main object of investigation.

*Area of Occurrence.*—A band of this rock stretches across Diana, with a course somewhat north of east, forming the southern boundary of the

Diana-Pitcairn limestone belt. The line of junction of these two rocks is clearly defined, but such is not the case on the other sides of the gabbro, as the rock undergoes decided modification, which renders its delimitation a matter of difficulty. The clearly recognizable mass of the rock has been traced from near Natural Bridge to a point three or four miles east of Harrisville, a distance of nearly or quite twenty miles. On account of the modifications mentioned the southern boundary of the mass is uncertain, but an average width of about four miles may be taken as a minimum.

*Appearance in the Field.*—Over a large proportion of the gabbro belt outcrops are abundant. The rock surface usually presents flowing contours, with something the aspect of roches moutonneés. This is particularly true in the eastern part of the belt, where the gabbro rises into considerable hills. In the vicinity of Natural Bridge the surface is flatter.

In many cases it is not easy to distinguish a weathered portion of the gabbro from coarse gneiss, but, as a rule, it is more massive and shows the prevalence of large feldspars. The most favorable exposures for an examination of the surface are those which have been smoothed by glacial action and since preserved from decay. Such a surface is usually a very light drab or gray, and has a somewhat porphyritic aspect; that is to say, the rock appears to consist largely of distinct feldspar individuals, ranging from a fraction of an inch up to an inch or more in diameter, held together by a varying amount of finer material.

In some cases the appearance of the surface recalls a rather fine conglomerate of great uniformity of grain and composition. Usually on such surfaces no constituent other than the feldspar can be determined, although dark minerals are shown in small grains.

*Characteristics of the Feldspar.*—In form the feldspar grains may be rounded or nearly rectangular, approaching their crystallographic outlines. A zonal structure is often shown, the marginal portion being nearly white, while the interior is gray or brown. The white band is about one-fourth as wide as the individual and the passage into the dark core is rather abrupt. There is a marked difference in the resistance offered to decay by these two portions of the feldspar. The dark area decomposes much the more readily, so that on glaciated surfaces which have been slightly weathered the feldspar grains have a depression in the central portion, surrounded by a rim of the white material. This mode of weathering is a great help in determining the true nature of doubtful exposures. Where the rock has been recently blasted it has a decided gray color, sometimes with a greenish tinge. Occasionally it becomes pink or red without deviating otherwise from the normal character. As is natural, such a surface has a more granular aspect than those which

have been glaciated, but the cleavage faces of the large feldspars are plainly seen. Other minerals, as a rule, are not determinable, but at some points there are considerable quantities of magnetic iron ore.

At most outcrops careful inspection shows a certain amount of parallelism in the arrangement of the feldspars. On the one hand this is very obscure, while on the other the rock becomes distinctly gneissoid.

*Microscopic Characteristics and mineralogic Composition.*—Microscopic sections show that the rock, as indicated in the hand specimens, consists chiefly of feldspar. The more typical specimens have cores of well twinned plagioclase, surrounded by a margin usually composed of microperthite. In such cases the fine tongues and spindles of the microperthite correspond optically with the material of the core, while the inclosing feldspar is more acid, as indicated by its lower interference colors. The basic character of the core accounts for its more ready disintegration, as seen in the field, while its dark color is explained by the presence of inclusions of magnetite.

The same microsections generally show other feldspar individuals consisting wholly of microperthite, and comparison of different sections shows that the microperthite may increase till it becomes the only feldspathic constituent.

The low extinctions and interference colors of the feldspars, as well as a mean index of refraction lower than that of quartz, as measured by Becke's method, show that the plagioclase is near the albite end of the series. The high percentage of soda shown by the analysis points to the same conclusion. Anorthoclase may well be preeent, but its separation has not been attempted.

Of ferro-magnesian constituents, monoclinic pyroxene is largely predominant, hornblende filling a very minor role and biotite rarely present. The pyroxene is usually deep green and non-pleochroic. The diallagic parting is absent, though a fibrous structure is sometimes shown. The mineral is always in irregular grains, and usually in small amount as compared with the feldspar. Magnetite is generally seen, ranging from the small inclusions in the feldspar up to irregular masses of considerable size. These may constitute so large a proportion of the rock as to render it a considerable ore body. Slender prisms of apatite are not uncommon. Quartz also appears in a number of sections, but there is reason for believing that some of it is secondary. Other constituents of minor importance are more common in certain modified portions of the rock. They will be referred to in the sequel.

The most striking feature shown under the microscope is a beautifully developed cataclastic structure. This is never lacking, though varying in different specimens. When least marked, the feldspars are separated

by narrow bands of fragmental grains, while the large individuals have very strong undulatory extinction. From such cases there is a gradation up to a complete crushing of the rock to a mass of minute grains, with only here and there a small residual core.

*Chemical Analyses.*—The analyses given below show that the microperthitic variety is rather too acid to be classed as a member of the gabbro family, as might be expected from its mineralogic aspect in thin sections, but there is no doubt of its geologic continuity with the more basic phase. They are different portions of a single intrusive mass and owe their differences to magmatic variations. It is by no means easy to determine in the field which is the prevailing type, but the facts at hand point strongly to the preponderance of the basic rock; hence the use of the name gabbro for the intrusion. In fact, the employment of this term would be justifiable even were the acid phase more abundant in this particular mass, inasmuch as the presence of a large quantity of the basic phase points so strongly to the conclusion that the entire mass belongs to the great gabbro intrusions of the region.

| | I. | II. |
|---|---|---|
| $SiO_2$ | 57.00 | 65.65 |
| $Al_2O_3$ | 16.01 | 16.84 |
| $FeO$ | 10.30 | 4.01 |
| $MgO$ | 1.62 | 0.13 |
| $CaO$ | 6.20 | 2.47 |
| $K_2O$ | 3.53 | 5.04 |
| $Na_2O$ | 4.35 | 5.27 |
| $H_2O$ | .15 | .30 |
| Totals | 99.16 | 99.71 |

I. Average sample of the ordinary basic variety; from Natural Bridge.

II. Acid variety, in section, largely composed of microperthite; from near Harrisville.

### *RELATION OF GABBRO TO LIMESTONE.*

*Character of the Transition.*—As previously stated, the northern boundary of the gabbro belt is clearly defined, being the line of its contact with the crystalline limestone series. It is not meant to imply that the precise location of this boundary has been determined throughout its entire length, for such is not the case, but merely that there is nothing like a transition between the two formations, the passage from one to the other being abrupt. As some portions of the gabbro might be taken for metamorphosed sediments, it is important to establish the true nature of this contact in order to justify the conclusion that the rock is igneous.

*Character of the Contact.*—Many absolute contacts have been examined, while in even more cases the two formations have been observed very

close together, although the line of junction was not exposed. These observations show that the contact is extremely irregular, presenting all the characteristic features produced by the intrusion of an igneous rock.

In the vicinity of Natural Bridge the contact is shown on a horizontal surface, forming a very irregular line, the gabbro sending out broad extensions into the limestone. Sometimes the latter rock cuts off portions of the gabbro from the main body, forming isolated patches. Narrow, sharply defined dikes of the gabbro have not been observed, the extensions being broad and irregular.

These contacts, however, though evidently irruptive, are not as striking as those presented in vertical sections. A most favorable locality for observing one of the latter is in a cliff on the west shore of Bonaparte lake. It is probable that this is the locality referred to by Van Hise* in his brief account of the region, as it corresponds closely to a description of the latter point given to the writer by the late Professor G. H. Williams shortly before his death. The gabbro here exposed may not be continuous on the surface with the main body; but if not, there is no doubt of their unity, so that the bearing of the facts remains the same in either event.

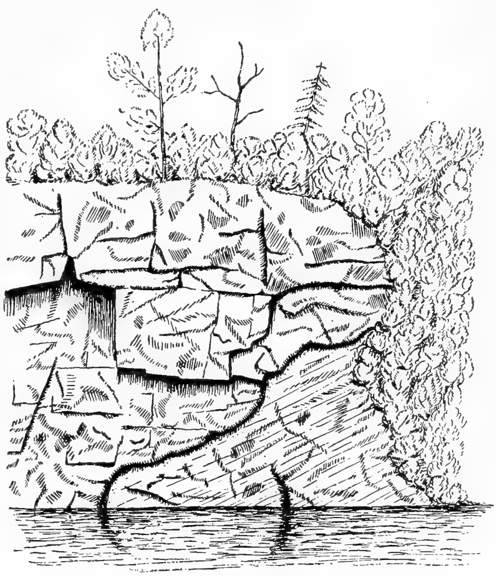


FIGURE 4.—*Gabbro-Limestone Contact. Lake Bonaparte.*
The drawing is made from a photograph.

The cliff referred to rises almost vertically out of the water to a height of sixty or seventy feet. Near its base the limestone is exposed clearly banded, but the mass of the cliff consists of gabbro, which cuts across the banding of the limestone in a sinuous line (see figure 4). At one point a wedge of limestone projects into the gabbro a distance of three feet. The limestone extends to the top of the cliff, but is cut off again by the gabbro a short distance along the face. These phenomena are repeated several times at this point and elsewhere along the lake shore, the gabbro cutting through the limestone again and

*Bulletin 86, U. S. Geol. Survey, p. 399.

again. It would be impossible to examine these outcrops without being convinced of the irruptive nature of the contact.

If any further structural evidence were needed to substantiate this view, it would be afforded by the presence of included masses of the older rocks in the intrusive. These are shown on a small scale near Natural Bridge, but a more instructive example occurs about a mile southeast of Harrisville. Here the gabbro contains abundant inclusions of fine grained, laminated gneiss, such as occurs interbedded with the limestone. These inclusions vary from a few inches to several yards in diameter. The lamination in the different blocks has different directions. The outline is usually rather irregular and the boundary between the inclusion and the gabbro is very sharp, with no trace of gradation between them (see figure 5). Sometimes the gabbro shows a banding near an inclusion and parallel to the side of the latter. There can hardly be a doubt that this is an original structure caused by the flowing of the molten magma around the solid inclusion (see figure 6). These facts clearly prove that the blocks of fine rock are inclusions and not of the nature of segregations. As they correspond in character to the gneisses of the limestone series, they furnish another proof of the intrusive character of the gabbro.

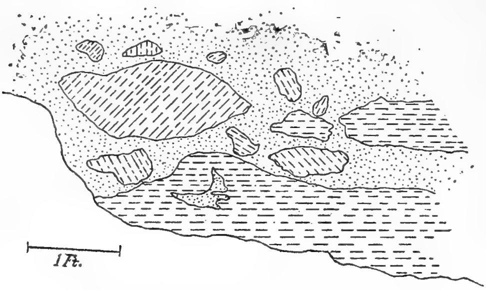



FIGURE 5.—*Inclusions of Gneiss in Gabbro.*

The drawing is made from photograph and field sketch procured one mile northeast of Harrisville.

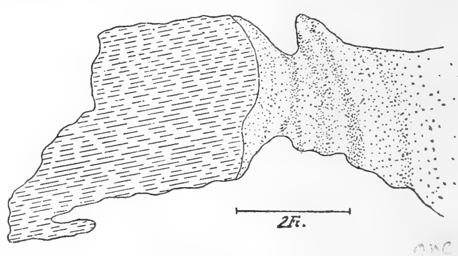



FIGURE 6.—*Banding of Gabbro parallel to Side of Gabbro Inclusion.*

The exposure, which is one mile southeast of Harrisville, is bounded by gravel, and the drawing is from a photograph and field sketch.

Less conclusive, but of a confirmatory nature, is the fact that at varying distances north of the main belt of gabbro there are numerous bosses cutting the limestone, which seem to bear an important relation to the former rock. These are generally quite small, but sometimes attain considerable dimensions. The rock of these bosses is quite different from the ordinary gabbro, but closely resembles certain phases of the latter yet to be described.

This resemblance is such that there can be little doubt that the bosses are offshoots from the main mass of gabbro, which owe their modified character to the different conditions under which they have solidified. It should be noted, however, that some of these bosses may be offshoots of the granite which lies to the north.

*Contact-metamorphism.*—While the structural evidence is in itself sufficient to justify the conclusion that the gabbro is intrusive in the limestone, there is no lack of substantiation in the way of mineralogic changes. On the contrary, wherever the two formations are observed in actual contact there is seen a considerable amount of contact-metamorphism, both endomorphic and exomorphic.

These changes, though varying in minor details from point to point, are on the whole of a rather uniform character, so that some of them may be described as a whole and others may be represented by a few typical localities.

Endomorphic Changes.—When the gabbro is examined near the contact it is found to be finer grained than the normal rock, though this is a rule to which there are abundant exceptions. At the same time the feldspar often becomes bleached to a light gray or white, and there may be an increase in the amount of dark constituents. The result of these changes is a rock finer than the normal gabbro, and, as a whole, lighter colored, but dotted over with numerous black spots.

Microsections from these portions of the gabbro often have the pyroxene in larger grains than in the normal rock, and the grains are in many cases bordered by scales of green hornblende. This hornblende looks like a secondary product, but the evidence in support of such a supposition is not as strong as in the case already described. The most striking and characteristic feature of these marginal portions of the rock is the presence of titanite, often in very considerable quantity. This mineral is usually in irregular grains of small size, several of which may be aggregated, forming patches two or three millimeters in diameter. It is noticeable also that sections from this part of the rock show much less granulation of the minerals.

The phenomena shown in the marginal portions of the main body of gabbro are largely repeated in the bosses lying beyond its northern boundary, but they, on account of their small size, have the marginal character throughout. This accounts for the variation from the normal type shown by the rocks of these bosses, and emphasizes the probability of their being offshoots from the main body. These changes in the character of the gabbro might be regarded as an example of the variation from point to point so often shown by members of the gabbro family and other basic rocks, but this supposition is completely negatived by the

fact that the changes always appear as the limestone is approached and have not been seen in any other part of the rock.

Exomorphic Changes.—Decidedly more marked than in the gabbro, are the mineralogic changes in the adjacent limestone. A good example is furnished by the contact, previously referred to, in the cliff on Bonaparte lake. The gabbro at this point shows the ordinary marginal character. The limestone at a distance from the contact is distinctly banded, but as it approaches within three or four feet of the gabbro the banding disappears and the limestone becomes a uniform white. Immediately adjoining the gabbro is a zone composed of a fibrous white mineral, with abundant grains of a green mineral. This zone varies in width from an inch up to a foot, and the relative porportions of the different minerals varies in different parts. The minerals sometimes show a banded arrangement which is wholly discordant with the original banding of the limestone, but is parallel to the line of contact. This zone is totally different from either of the rocks between which it lies, and is without doubt a product of the action of the heated intrusion upon the limestone. The contact-zone seems rather more closely linked to the intrusive rock than to the limestone; but it is doubtless to be regarded as an altered portion of the latter, or perhaps more accurately as a product of interaction, deriving some of its constituents from both rocks, and thus in a sense intermediate between the two. Sections from this zone show green pyroxene and wollastonite as prevailing minerals, with smaller quantities of titanite and garnet.

Similar contacts may be seen at several other places along the shore of Bonaparte lake, and at many points elsewhere in the region. They are particularly marked in the case of the small bosses lying to the north of the main gabbro body.

In most of these exposures the phenomena are somewhat obscured by weathering, but this difficulty is removed at several points about one mile east of Natural Bridge. The well known minerals from this locality are such as to suggest the possibility of the presence of a contact-zone, and, indeed, it has been stated* that they occur "near the juncture of crystalline and sedimentary rocks." As a matter of fact, the most important openings from which these minerals have been collected were found by the writer to be immediately on the contact of the gabbro and limestone. Some of these pits have been opened to a depth of ten feet or more, with a length of fifteen or twenty feet, and though several have been filled in with bowlders gathered from adjacent fields, two or three are open to inspection and furnish very perfect sections of the contact, with an almost complete absence of weathering.

* Dana's System of Mineralogy, sixth edition, p. 1063.

In a pit on the Ashmore farm the best exposure occurs, showing both the limestone and gabbro. The latter rock has the same character as the marginal portions seen elsewhere, being comparatively fine, light colored and showing many black spots. Between the gabbro and the limestone there is, as at Bonaparte lake, an intermediate zone of contact-products, usually from one to two feet wide. This varies in precise detail in various parts of the pit, but where best shown there is, next to and grading into the gabbro, a layer containing much wollastonite. Next to this, on the other side, is a mixture of feldspar, pyroxene, scapolite, sphene, zircon, etcetera. Then comes coarse calcite with much pyroxene, and, finally, fairly pure, coarse calcite, which shades off into the ordinary limestone. The different layers are not at all distinct, but shade into each other and vary greatly in relative and absolute thickness. At another point the portion of the contact-zone next to the gabbro consists of almost pure scapolite instead of wollastonite. Irregular seams in the gabbro are abundant, and are lined with pyroxene, orthoclase and scapolite. Similar facts are presented in the other pits of the vicinity, but owing to the causes above named they are less clearly shown.

The position of this zone, following all the irregularities of the contact between the two formations, is sufficient proof that it has been formed by the action of the one upon the other. This action can be explained in no other way than as a case of contact-metamorphism resulting from the intrusion of the gabbro into the limestone. This conclusion is entirely supported by the mineralogic composition of the contact-zone, as the species named are all recognized contact-minerals, particularly in limestones.

No extended study of the minerals of the contact has been made, and their presence in most mineral collections renders unnecessary a detailed description, but it may be well to state some of their more important features.

Orthoclase occurs in implanted crystals and irregular masses in the limestone. The crystals are opaque white and range from very small size up to two inches in greatest diameter. They are tabular, parallel to the clinopinacoid, and measurements made with the hand goniometer show the presence of the following faces (using Dana's lettering): *b*, *c*, *m*, *n*, *o*, *z*, *y*.

The determination as orthoclase rather than microcline is based not upon measurement, but upon extinction angles and the absence of twinning in cleavage plates. Such examination does, however, show the presence of the microperthitic intergrowth. It also shows in the orthoclase from one opening great quantities of fluid inclusions. These inclusions are arranged in rows, and the cavities are so close together that

with low powers these rows look quite like the rutile threads in quartz. Most of the rows are, in basal section, parallel to *b*. In the symmetry plane the rows are less regular, but usually parallel to *c* and *x*.

The irregular masses of orthoclase which lie imbedded in calcite differ from the foregoing in being semitransparent, with a bluish tinge. Cleavage fragments indicate that intergrown with the orthoclase there are parallel plates of plagioclase.

Pyroxene is extremely abundant, and is found both implanted in the fissures of the gabbro and imbedded in the adjacent limestone. In the latter position it sometimes forms individuals two or three inches long and one inch in diameter. The implanted crystals are usually smaller. The color is dark green or black. The faces on the material collected are so imperfect that measurements could not be made, but apparently the crystals are rather simple, probably combinations of *b*, *c*, *m*, *n*, and *o*.

Wollastonite has not been found with crystal form. It occurs in irregular fibrous masses, often several inches in greatest diameter, pure white, and with a pearly luster.

Scapolite may be in layer-like masses or distinct crystals. The masses are colorless, with a slightly fibrous appearance, on the vitreous cleavage surface. The crystals, which have not been found with a length of more than an inch, are either white, gray or pale blue. They show the forms *a*, *m*, *r* and *z*, some crystals showing clearly the pyramidal hemihedrism.

Titanite occurs both in the zone of mixed composition and imbedded in pure calcite. The crystals are very perfect, with bright faces and deep reddish brown color. They may be almost microscopic in size or as much as an inch in diameter. They belong to the variety lederite, and show the faces *c*, *m* and *n*. A specimen in the Hamilton College collection from this locality shows the polysynthetic twinning described by Williams* as occurring on titanite from the adjoining town of Pitcairn.

Zircon occurs in the same manner as the sphene. The crystals are simple, showing only *m*, *p* and *n*. They are often very long and slender. The best specimen obtained was imbedded in calcite; it is about an inch long and doubly terminated. The color in all the specimens inclines to lavender, which sometimes becomes very marked.

Other minerals, in particular phlogopite, are present, but as they occur disseminated through the limestone almost everywhere they cannot be regarded as contact-products. In this connection mention should be made of the gieseckite, of which fine specimens are found under and near the natural bridge. The large hexagonal crystals of this mineral compare very closely with the form of nepheline, as shown by Blum, who regards the gieseckite as a pseudomorph after the latter species. If this

* Am. Jour. Sci., third series, vol. xxix, p. 486.

conclusion is correct nepheline should probably be added to the list of contact-minerals, for the points where it occurs are very close to the contact, though not absolutely on it. It must be said, however, against such a supposition that there has been found neither gieseckite nor nepheline at the actual contacts examined. The question as to the origin of these minerals is thus still open, with the probabilities as just stated, but of the presence of contact-metamorphism there is not the slightest doubt.

*Metamorphism of the Limestones as a Whole.*—This brief consideration of contact-action in the limestones brings up the question as to how much of the general metamorphism of the limestone series has resulted from the intrusion of the great gabbro masses. That the crystallization of the rocks is a result of contact action on a large scale was first suggested by Van Hise,* and the idea has been referred to by Professor Kemp in the preceding paper. In Essex county, where the limestone occurs in isolated patches completely surrounded by gabbro, the inference seems quite justifiable; but great caution should be used in applying this explanation to the region here considered, where the conditions are very different, as shown in the foregoing. Instead of small patches, we have extensive areas of limestone, while the rocks of known intrusive nature are quite limited in area as compared with Essex county. So far as examination has been made, the limestone is thoroughly crystalline throughout, the degree of crystallization not depending upon the position in the belt nor the proximity of intrusives, except in the case of a narrow zone in close contact with the latter. If the metamorphism were caused by the intrusion we should expect to find a different state of affairs, a more complete crystallization in the neighborhood of the igneous rock; but even did such a relation exist it would seem very doubtful whether the igneous rock present would afford a sufficient cause for the complete crystallization of such extensive areas of limestone and imbedded gneiss. Should future investigation, however, prove a large percentage of the massive gneisses to be of intrusive nature, this difficulty would be considerably reduced. When the actual contact-zones are considered, their narrowness and sharpness of definition are striking. Instead of a gradual increase in crystallization and number of different minerals as the igneous rock is approached, there is no perceptible change till within a few feet or inches of the latter, and then there is a distinct zone of contact-products. Were the intrusion the cause of general metamorphism it would seem that the contact-zone would be much wider and would shade gradually into the ordinary limestone.

In this connection much interest attaches to an isolated patch of lime-

* Bulletin 86, U. S. Geol. Survey, p. 399.

stone which lies about two miles east of Diana Center and is entirely surrounded by gabbro. It might be expected that an intrusion capable of completely metamorphosing many square miles of limestone would convert this area of a few square rods into a mass of contact minerals, and yet the limestone of this patch differs in no considerable degree from that of the larger belts.

These facts appear to render very doubtful the hypothesis of contact-metamorphism on a large scale, although the intrusive rocks may have considerably aided the process of crystallization. It is a matter of great difficulty to determine the relative efficiency of different agents, and opinions will doubtless show much variance.

That the rocks of the limestone series have been subjected to intense mechanical strain with consequent plication and crushing has already been pointed out. It seems well within the bounds of probability to assign to this cause much, if not most, of the crystallization of the limestone series, while what has been called static metamorphism may have contributed to the final result.

### *RELATION OF GABBRO TO GNEISS.*

Of great importance in unraveling the geology of the region is the relation subsisting between the gabbro and the adjacent gneisses which bound it on the west and south. This importance lies not so much in the phenomena presented as affecting this particular field, but rather in the clues afforded for solving problems in other parts of the Adirondack region.

In the vicinity of Harrisville considerable breaks in the series of outcrops between the gabbros and the massive gneisses to the south have thus far prevented a determination of their relations; but near Natural Bridge the conditions are more favorable. Between this village and Carthage, ten miles west, the country is occupied by a red gneiss, rather fine grained, and not, as a rule, strongly foliated. Starting from the normal gabbro at Natural Bridge and passing toward this red gneiss the natural expectation, based upon the appearance of the two rocks, would be to find the one cutting, or superimposed upon, the other; but such is not the case. On the contrary, about two miles west of the village the gabbro undergoes a conspicuous modification. It becomes gradually finer grained and gneissoid, and changes from gray to red. In other words, it passes gradually into the red gneiss, which must therefore be regarded as a modified portion of the gabbro.

The change, while gradual, as traced from one outcrop to another, is rather abrupt, as regards the width of the intermediate zone in comparison with the extent of the two varieties of the rock. This zone is

perhaps half a mile wide, though, in the nature of the case, not clearly defined.

The red gneiss has not been examined over any considerable area, but, so far as seen, the change in the gabbro at all points has been so considerable that no unmodified portions have been found in the red gneiss. Still, many specimens of the latter show traces of their origin, being augen-gneisses on a small scale, with augen of residual feldspar grains sometimes a quarter of an inch in diameter.

Sections of the red gneiss under the microscope differ from the ordinary gabbro only in a more complete granulation of the constituents, with the formation of a little finely divided hematite, which gives the red color to the rock, and often an increase in the amount of quartz present.

It seems, then, clearly established that this red gneiss in the town of Wilna is continuous with, and a modification of, the gabbro. South and east of Natural Bridge, in the vicinity of Oswegatchie Settlement, a similar transition is found, but differing somewhat in detail. The gabbro again passes into a reddish gneiss, but the latter is much coaser than that of Wilna, and contains a conspicuous amount of hornblende. The outcrops in this direction are less satisfactory than in the previous case and the evidence is not so conclusive. Still, the inference seems to be wholly justified that here again there is a gradual transition from normal gabbro into red gneiss, the two rocks being simply different phases of the same mass. In neither of the cases would it be possible to determine with any certainty the origin of the gneisses were the zone of transition hidden, and it is probable that, in the absence of this zone, the derivation of the gneiss from the gabbro would hardly suggest itself to an investigator in the field, though it might be indicated by microscopic and chemical examination.

This being the case, it is natural to infer that all of the gneiss which extends along the southern side of the gabbro belt may be a modification of the gabbro itself, although the absolute establishment of this inference as a fact may be a matter of great difficulty. These facts indicate how difficult it is to map accurately this and other portions of the Adirondack region, for as yet no method has been found for making an accurate distinction between the gneisses which may be modified portions of the gabbro and those of different origin.

## Diabase.

At widely scattered points in Diana several outcrops of diabase have been noted. It forms irregular bosses or sheets, more rarely clearly defined dikes, usually cutting the limestone or gabbro, only a single intrusion in granite having been found. The rock exists in such small

quantity as to be of little importance in itself, while the fact that it cuts all the other rocks renders it useless as a factor in working out their relations. In microsections it usually shows fairly perfect ophitic structure, with the augite in a granulitic condition, instead of in large masses. The only uncommon mineralogic features are the occasional presence of garnet, which seems to be an original constituent, and the occurence of some hypersthene. When the latter is in considerable amount and, as is not uncommon, the ophitic structure disappears, there is a close resemblance between the diabase and the hypersthene-gabbro above described. This fact, combined with their field characters, suggests a close connection between the two rocks.

## Summary.

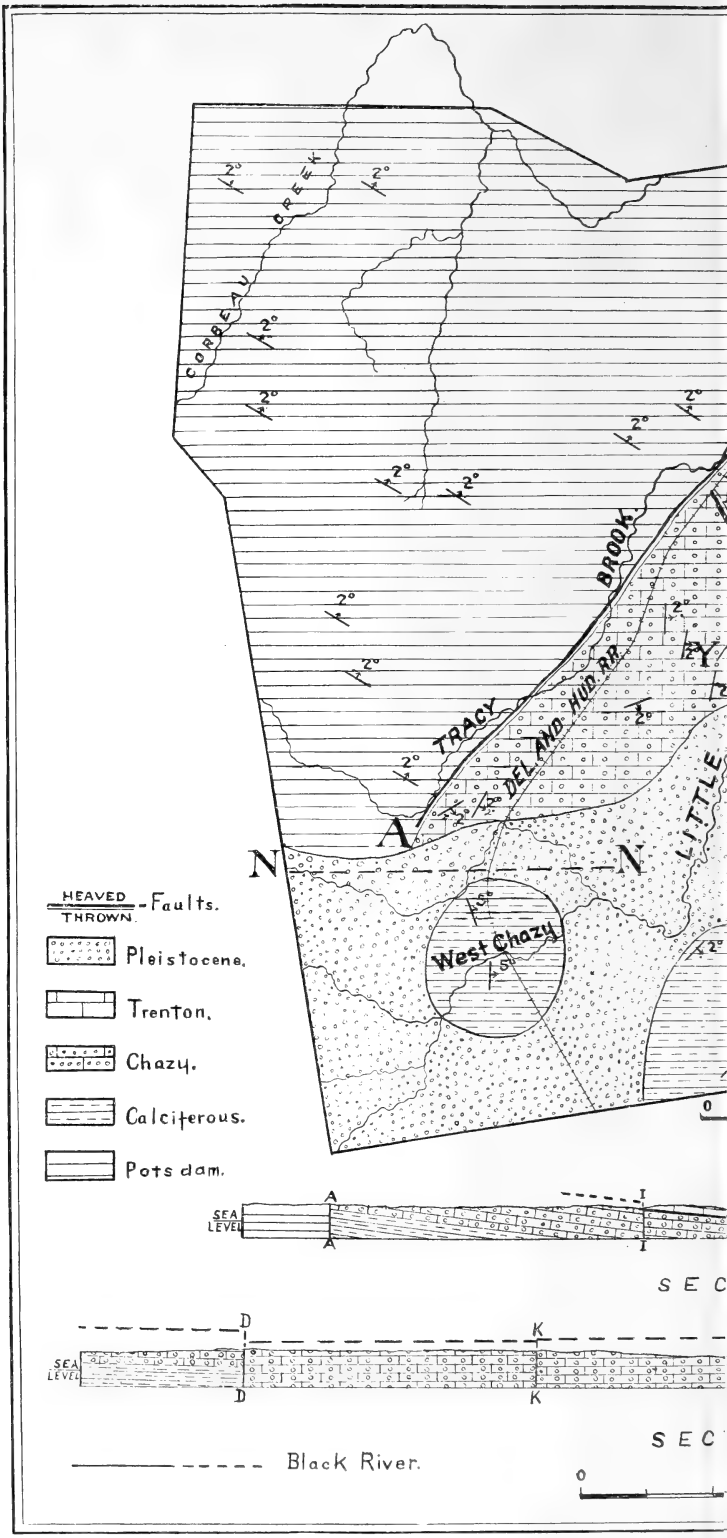
The region considered contains extensive belts of crystalline limestones with interbedded gneisses, constituting a series which can hardly be regarded as of other than sedimentary origin. Certain hornblendic and pyroxenic gneisses constantly associated with the limestone may be in part modified igneous rocks.

There are present several varieties of undoubted igneous rocks, granite and gabbro in large amount, with minor diorite and diabase. They are all younger than, and intrusive in, the limestone series, producing marked contact-metamorphism in the latter. The ages of these intrusions with reference to each other are not clearly determined except in the case of the diabase, which is evidently the youngest.

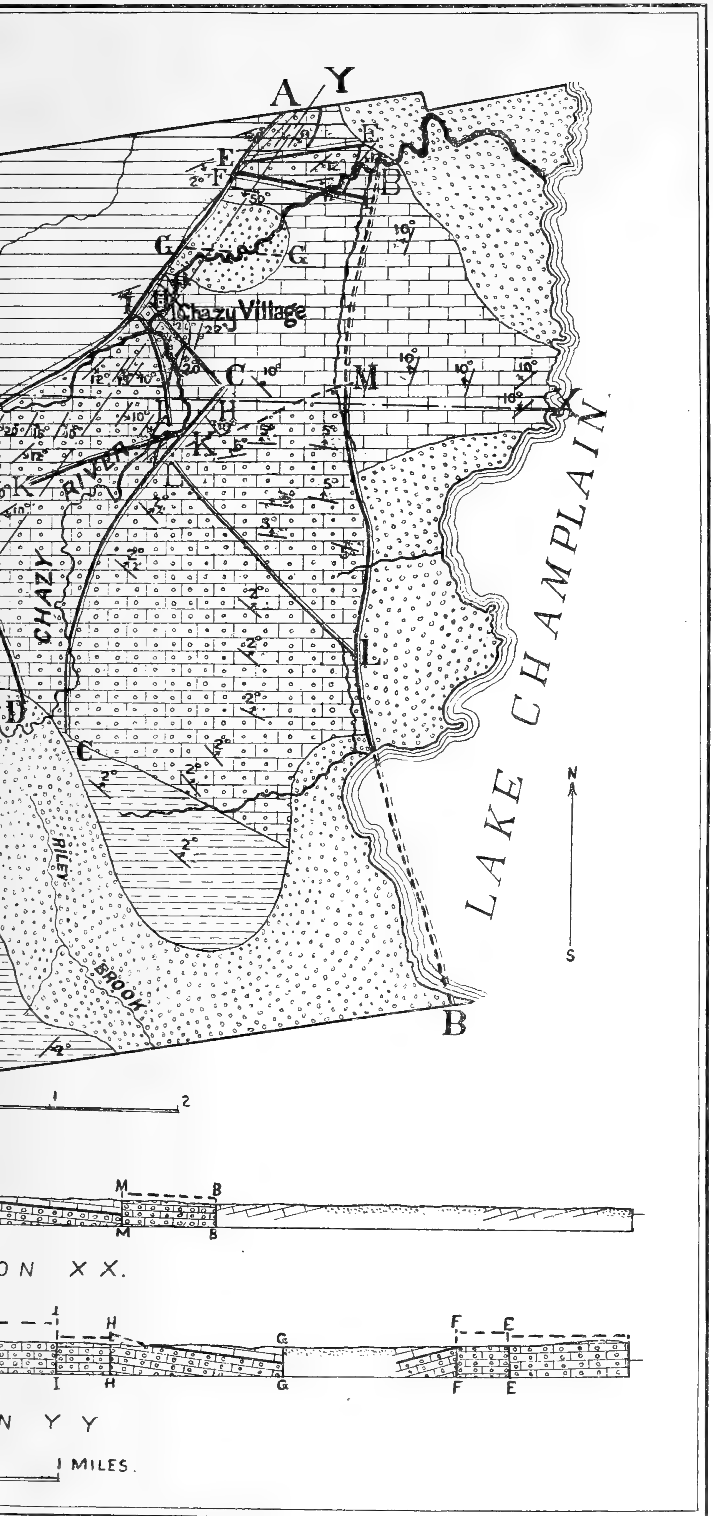
Besides these rocks whose origin is clear, there are wide areas of gneisses whose origin and relation to the other formations are largely a matter of doubt. Portions of these gneisses form the basal parts of the limestone series. Other portions are intrusive, as shown by the granitic boundary of one of the belts and by the passage of gabbro into a gneissoid form.

Whether all of the gneisses belong in the one or the other of these classes, or whether still other portions are older than, and unconformable beneath, the limestone series, it is as yet impossible to say. At present we have no absolute knowledge of any formation in the region which is older than the limestone series.

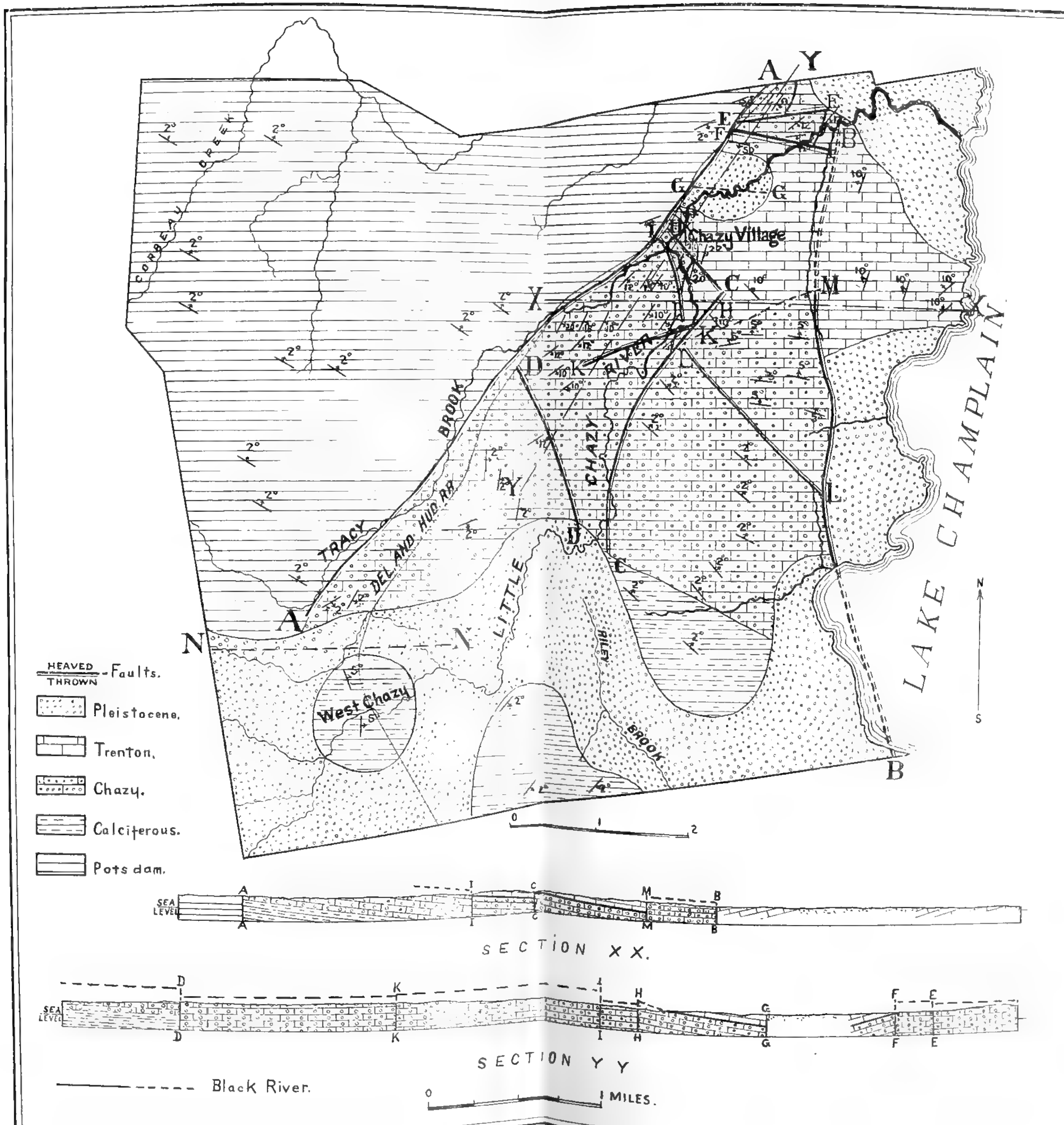
It has been suggested that the metamorphism of the limestone is a result of the intrusion of the gabbro masses which are so extensive in the Adirondack region; but the great extent of the metamorphosed series, the completeness of crystallization in all parts, the narrow and sharply defined contact-zones and the comparatively small quantity of known intrusive rocks combine to render the explanation rather improbable as applied to this particular area. On the other hand, the evidences of great mechanical disturbances justify the conclusion that the metamorphism is largely dynamic.




GEOLOGIC MAP OF CHAZY TOWI




CLINTON COUNTY, NEW YORK.




GEOLOGIC MAP OF CHAZY TOWNSHIP, CLINTON COUNTY, NEW YORK.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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# FAULTS OF CHAZY TOWNSHIP, CLINTON COUNTY, NEW YORK

BY HENRY P. CUSHING

*(Read before the Society December 27, 1894)*

CONTENTS



## SITUATION AND GENERAL FEATURES OF THE DISTRICT.

Chazy township is situated in the northeastern part of Clinton county, bordering on lake Champlain, with Champlain township intervening between it and the Canada line. The county is separable topographically

into three divisions—a hilly region in the southwest, a high plain sloping north from the hills, and a strip of lowland of varying width along the lake-shore, whose rise to the level of the high plain is quite abrupt. Chazy township belongs, for the most part, in this latter subdivision, but in its western portion the level rises rapidly to that of the high plain to the west.

The minor topographic features of the township are dependent to a surprising degree on the faults to be described. These features are more or less obscured by drift, but in the vicinity of Chazy village this covering is so much less marked than elsewhere along the low strip that the relations can be readily worked out. The dip here is frequently pronounced, so that the strata outcrop in linear ridges whose crests are the cut-off edges of the various more resistant layers. When followed along the strike, these ridges are found to be sharply intersected at various intervals by low marshy tracts, beyond which other ridges appear in like manner, but do not correspond with their predecessors. Many of the lines of faulting to be described are occupied by marshes of this character. Furthermore, the main streams occupy fault-lines to a very great extent.

## The Formations represented.

Leaving out of consideration the Pleistocene deposits, the geologic formations exposed at the surface in the township may be tabulated as in the adjacent table.

Of these formations the Chazy and the Black River limestones are well exposed, are everywhere fossiliferous and were therefore very serviceable in working out the stratigraphy. This was true in a marked degree of the Black River limestone, which, due to its slight thickness, furnished an especially valuable datum point wherever it appeared. On the other hand, the Trenton and Calciferous are but meagerly and unsatisfactorily exposed, while the frequent outcrops of the Potsdam are of little service, owing to the lithologic similarity of the mass, the scarcity of fossils and the lack of exact knowledge of its total thickness. This latter must itself be very variable in the region, as the Potsdam is a shore deposit laid down on an uneven floor. One exception must be noted to this general statement concerning the Potsdam, namely, that the passage-beds, separating it from the Calciferous are lithologically distinct from either, and it is believed furnish a recognizable stratigraphic horizon. Mention should be made here of the admirable stratigraphic work done on the Chazy in the vicinity of Chazy village by Messrs Brainard and Seeley, which served as a starting point for this investigation, and to which the reader is referred for details.*

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*Am. Geologist, November, 1888, pp. 323–330.

*Formations exposed in Chazy Township.*

| Formation. | Character. | Thickness. |
|---|---|---|
| Trenton ...... | Black, slaty limestone, highly fossiliferous at certain horizons. | Unknown in the Lake Champlain region, but clearly several hundred feet at least. |
| Black River... | Black, slaty limestone, more massive than the overlying Trenton; sparingly fossiliferous, but with a characteristic fauna. | From 30 to 50 feet. |
| Chazy ........ | Massive beds of limestone, the whole separable into a lower, a middle and an upper division, each well marked lithologically and paleontologically.* | About 750 feet. The lower, middle and upper divisions have a thickness of 350, 250 and 150 feet respectively.* |
| Calciferous .... | Massive, gray, siliceous limestones and dolomites, which are sparingly fossiliferous. | Not known for this vicinity. At the head of lake Champlain the formation has a measured thickness of 1,800 feet.† |
| Potsdam...... | Massive beds of sandstone, of red, white or yellow-brown color and varying degree of induration, with conglomerate and arkose at the base, and passage-beds to the Calciferous at the summit. | Unknown, but at least several hundred feet. Mr Walcott has measured sections of 250 and 350 feet respectively at Chateaugay chasm and Ausable chasm, which represent merely unknown portions of the whole. ‡ |

## The Faults.

### *THEIR PREVALENCE IN THE REGION.*

Wherever any bit of the region bordering on lake Champlain has been mapped in detail one or more faults have been disclosed. Sometimes the fault-line itself is shown in section, but more commonly its presence is indicated by the structure merely. The number of faults already mentioned or mapped in the region must be 20 or 30, yet they probably represent only a small proportion of those which exist. While faults

* Brainard and Seeley: Am. Geologist, November, 1888, p. 324.
† Brainard and Seeley: Bull. Am. Mus. Nat. Hist., vol. iii, no. 1, p. 2.
‡ C. D. Walcott: Bull. U. S. Geol. Survey, no. 81, pp. 343, 344.

abound, in general folds are absent. This is true in a marked degree of the region at the lower end of the lake. At the upper end of the lake in Vermont, as the line of the great thrust fault is neared, the rocks are found to be folded as well as faulted.* Away from this vicinity, however, folds do not appear, or else are extremely gentle. In each fault-block the dip is steadily and persistently in one direction, and the various strata follow one another in regular order with no repetition.

### *FEATURES AND CLASSIFICATION OF THE FAULTS.*

In none of the faults occurring in Chazy township is the fault-plane itself open to inspection. Elsewhere on lake Champlain, however, fault-planes are visible, and when this is the case they are seen to be nearly or quite vertical. Attempts to determine the hade of the Chazy faults geometrically give very unsatisfactory results, because data of sufficient precision are not to be obtained, but an approach to verticality is suggested by them without, however, indicating whether such hade as exists is to the up or the down throw. There is at the present time no evidence at hand to show that in respect to hade and throw there is more than one class of faults in the region.

In going from end to end of lake Champlain a succession of faults produces a frequent repetition, in whole or in part, of the lower Paleozoic series. Locally many faults have been mapped, but no attempt has as yet been made to trace the faults from one place to another in order to determine their extent. It is indeed questionable whether this is possible in any considerable measure. In that portion of the region directly under consideration the faults may be conveniently grouped in three classes, but there is as yet no evidence that this grouping may be applied to the region as a whole. For the purpose of description, they may be referred to as of the first, second and third classes, and the consideration of their differences will more appropriately come in after the faults themselves have been described.†

### *FAULTS OF THE FIRST CLASS.*

*Fault A-A.*—The most pronounced structural feature in Chazy township is the great fault whose position corresponds closely with the line of Tracy brook from a point one mile north of West Chazy village, where

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* See Brainard and Seeley: Bull. Am. Mus. Nat. Hist., vol. iii, no. 1, pp. 8, 9.

† Some references to faults in other parts of the Lake Champlain region are appended. The list makes no pretense of being complete.

E. Emmons: Geol. of New York, vol. ii, p. 274.

Brainard and Seeley: Am. Geologist, November, 1888, p. 326.

Brainard and Seeley: Bull. Am. Mus. Nat. Hist., vol. iii, no. 1, pp. 5, 8, 11, 15, 18, 21.

C. D. Walcott: Bull. 81, U. S. Geol. Survey, p. 344.

T. G. White: Trans. New York Acad. Sci., vol. xiii, p. 225.

the brook turns at an abrupt angle into the fault line, to Chazy village, where the brook joins the Little Chazy river. Beyond Chazy village the river leaves the fault-line, but the railroad closely follows it to the township line. The fault can be first recognized north of West Chazy, where the road crosses Tracy brook, and here ledges of Potsdam sandstone are exposed on the west side of the stream, while only a few rods away to the east, with very different strike, are beds well down in the lower division of the Chazy. To the south the further extension of the fault is concealed by a heavy covering of drift. To the north, however, it is readily traceable throughout the township. The heaved block on the west brings Potsdam sandstone to the surface in all outcrops. On the east the thrown block is much broken, especially in the vicinity of Chazy village, so that ledges of varying age abut against the fault-line, the range being from the lower Chazy up to the Black River limestone. Every vestige of the Calciferous is faulted out. This fault is traceable, with a great degree of probability more than half way across Champlain township next north of Chazy, giving it a known length of from eleven to twelve miles. In that township the Calciferous comes in, conformably overlying the Potsdam, on the west side of the fault.

The vertical throw of this fault cannot be accurately determined, owing to lack of knowledge concerning the thickness of the Calciferous here. Brainard and Seeley have shown that at the upper end of lake Champlain the Calciferous has a thickness of 1,800 feet, and that, while toward the lower end of the lake no complete exposures are found, the different members of the formation hold their thickness pretty persistently.* If this is assumed to be its thickness here, the fault has a throw of about 2,000 feet at Chazy village. The character of the rock exposed there on the west side of the fault is that of the passage-beds between the Potsdam and Calciferous, while on the east side are beds of the lower division of the Chazy, so that the throw of the fault is not much in excess of the thickness of the Calciferous.

In their work at Chazy village Brainard and Seeley recognized this fault and fully realized its importance.† Though they did not attempt to plot it or trace it for any distance, their map indicates its course for a mile and a half southwest from the village. The fault was also recognized by Mr Walcott when there, though he seems to have regarded its throw as of small amount and accounts otherwise for the non-appearance of the Calciferous.‡

*Fault C-C.*—At a varying distance of from one to two miles east of fault A-A is another great north-and-south fault, roughly parallel with it.

* Bull. Am. Mus. Nat. Hist., vol. iii, no 1, pp. 1–23.

† Am. Geologist, November, 1888, p. 327, and Bull. Am. Mus. Nat. His., vol. iii, no. 1, p. 13.

‡ Bull. 30, U. S. Geol. Surv., p. 24.

It has been traced for a distance of two miles and a half, but as it then passes at both ends into country heavily drift-covered, further tracing is impossible. Between it and A-A lies the zone of much faulting. To the east of it is a tolerably regular and nearly continuous section ranging from the upper Calciferous to the Black River limestone, with a dip and strike which correspond with those in the Potsdam west of A-A, while the varied dips and strikes in the shattered zone between the two faults bear no apparent relation to either. If, however, these two faults are considered as genetically connected—that is, as forming practically one fault, with the zone between regarded as merely an unusually wide, crushed strip—the apparent lack of relationship is at once explained. Both faults are dip-faults and the combined throw is about that estimated for the fault A-A, or 2,000 feet. The Little Chazy river follows the fault-line C-C for two miles, then, near Chazy village, passes from it to fault H-H, which it follows to A-A, where Tracy brook joins it.

*Fault B-B.*—This is a third great north-and-south dislocation, which is first discernible at a point about a mile and a half east of Chazy village, north of which point outcrops are too few and meager to permit of following it further in that direction. Its trend, however, suggests a possible junction with the fault A-A somewhere to the north. Where first recognizable the higher beds of the middle division of the Chazy are exposed on the west side of the fault-line, and outcrops of an horizon somewhere in the Trenton on the east side, these last lying at a level 100 feet lower than that of the beds across the fault-line. Outcrops on the east side of the line are few and far between, but the fault can be traced with tolerable certainty to the shore at Monty's bay, where it passes beneath the lake. It reappears on the opposite side of the bay and is traceable all the way across Beekmantown township, next south, into Plattsburgh township, a distance of between ten and eleven miles. Throughout Beekmantown township the entire Chazy is faulted out along this line. In north Beekmantown an horizon low down in the Trenton is exposed on the east side of the fault, and an unknown horizon in the Calciferous on the west side. Assuming that the thickness of the Chazy here is the same as in Chazy and Plattsburgh townships—that is, in the neighborhood of 750 feet—the throw of the fault here is an as yet unknown amount in excess of that. At the Plattsburgh-Beekmantown line the fault seems to divide, enclosing a much faulted block of Chazy and Black River limestone between the Calciferous and Trenton. Still farther south, at Bluff point in Plattsburgh, the Trenton is faulted down against the Chazy on the prolongation of this fault-line. If this prove to be the same fault its known length is increased an additional five miles.

*Summary of Faults of the first Class.*—The three faults just described

are the main dislocations of the vicinity. They differ from the remaining faults of the region, so far as the evidence goes, merely in magnitude. They are the main lines of displacement; the other faults are but minor breaks in the faulted blocks into which the great breaks divide the region. In this vicinity these great faults have a roughly north-and-south direction, but in the region as a whole there is no probability that this will be found to be the case.

*FAULTS OF THE SECOND CLASS.*

*Fault L-L.*—Two sets of facts indicate a break along the line L-L. First, the beds of middle Chazy age on both sides of the line have a much greater width of surface outcrop than their thickness entitles them to at the measured angle of dip; second, the angle of dip is abruptly increased along that line, otherwise being quite persistent on either side. It is probable that there is also repetition of a part of the series, but more detailed work than has yet been possible is necessary in order to furnish the proof. The fault is a strike-fault with downthrow to the south, and a throw certainly less than the thickness of the middle Chazy—250 feet, and probably considerably less.

*Fault M-M.*—North of L-L is another fault of the same character, bearing to the northeast instead of the southeast, and with the thrown block on the north instead of the south side. At the west end of the fault Black River limestone is exposed on the thrown side; beds of the middle division of the Chazy on the heaved side. The missing strata are at least 200 feet thick, and the dip and strike on the opposite sides of the fault-plane are quite unlike. At the eastern end of the fault middle Chazy beds on the south are brought up against Trenton on the north, the exact horizon in the latter being unknown. The Trenton limestone along lake Champlain has not yet been carefully studied. That the throw of the fault increases in amount from west to east is, however, clear from an inspection of the dip and strike on the two sides.

*Fault D-D.*—While it is uncertain whether this supposed fault belongs to the second or third group, as herein classified, its description may be conveniently given now.

The line of the fault is occupied by a wide marsh, so that an interval of half a mile separates the first outcrops on one side from those on the other. North of the marsh are beds of lower and middle Chazy age in normal relations to one another and with a strike normal to the line of the marsh. On the other hand, south of the marsh are found beds of lower Chazy age alone, with different strike and dip. It should be stated that in the triangular section of country enclosed between the faults A-A and D-D the relations are obscure and not yet fully worked out. Out-

crops are tolerably plentiful, disclosing no rocks of other age than lower Chazy. Accurate determinations of dip and strike are attended with much difficulty, but the data at hand suggest that faults are present. In the state of our knowledge the relations north and south of the marsh are best explained by the presence of a break of some sort somewhere beneath the marsh, with a downthrow to the north.

*Supposed Fault N-N.*—If the beds of lower Chazy age exposed just east of the southern end of fault A-A were prolonged southwestward in the direction of their strike they would pass to the west of the Calciferous exposures at West Chazy, which have an easterly dip. These Chazy beds, however, are tolerably near the fault-line of A-A, so that their inclination and strike may be merely local. A fault along the line N-N would make the relations between the two clear, but the evidence of its presence is slight.

*Summary of Faults of the second Class.*—Faults like L-L and M-M seem to be distinguishable from those of the first class in their inferior magnitude and extent. The evidence at hand indicates that they are subordinate to the main faults, and represent breaks in the blocks lying between them. If this conception be the true one, these faults of the second class should be limited each to a single main fault-block, should be cut off at the great faults and not pass across them. Proof that they are really so cut off is difficult to obtain, though the negative evidence all points in that direction.

### *FAULTS OF THE THIRD CLASS.*

*Fault E-E.*—The thrown block of the great fault A-A has suffered much minor dislocation, being separated into a series of small blocks by a number of faults, which are roughly normal to A-A. Near the fault-line, however, the confusion is so great as to preclude detailed mapping.

As the township is entered from the north along A-A, fault E-E, the first of the series, is met. North and south of the fault are ridges of middle and upper Chazy beds followed by the Black River limestone. The fault is a dip-fault with a heave of about 400 yards, the beds on the south side of the fault lying about that amount further east than the corresponding beds to the north. The amount of heave, taken in connection with the angle of dip, indicates a vertical throw for the fault of from 200 to 250 feet, with the downthrow on the north.

*Fault F-F.*—The ridges of rock south of fault E-E extend but a short distance southward, and are then abruptly cut off along the strike at the line F-F. Just south of this line outcrops are absent, except for a considerable knoll of Black River limestone which lies close to the railroad and very near fault-line A-A. It lies a full mile to the west of the Black

River limestone exposures north of F-F, so that a fault of great throw is indicated if this outcrop is taken as indicative of the normal relations along the fault-line. There are, however, at least two other outcrops of Black River limestone, and perhaps more, which occur at points farther south along fault A-A, between the Potsdam west of the fault and the Chazy east of it, and it may be that this outcrop under consideration should be classed with them as an extremely aberrant mass merely indicative of the great shattering which has taken place along A-A. If this be accepted as the true explanation, the only evidence we have of a fault at F-F is the sudden disappearance at that line of the ridges of Chazy limestone which lie north of it.

*Fault G-G.*—To the south of this knoll of Black River limestone no outcrops have been noted for a distance of half a mile, when the section exposed along the river at Chazy village, and in the village itself. is reached—a section showing the middle and upper Chazy followed by the Black River. The absence of outcrops makes the presence of a fault here purely conjectural, and the data at hand could be equally well explained by the presence of a synclinal trough running from fault F-F to the outcrops at Chazy village. The fault is preferred as the explanation merely because no other fold of the kind is known in the township.

*Fault H-H.*—Brainard and Seeley's detailed map of the vicinity of Chazy village commences on the north at the river section just mentioned, and extends thence for a mile to the south and a mile and a half to the southwest, showing faults H-H and I-I.* The map is exact in all respects, and may be profitably consulted for details. The fault-line H-H is occupied by the river for a portion of its length. Beyond the point where the river leaves it, its course is clearly indicated by the abrupt cutting off of the ridges of rock on the opposite sides of the line and by the *heave* † as well as by the change in amount of dip. The Black River limestone south of the fault lies 150 yards west of the same stratum north of the fault, as measured normal to the strike, or 250 yards distant along the fault-line. The south is therefore the thrown block, and the vertical displacement is not far from 200 feet.

*Fault I-I.*—The strike swerves somewhat toward the west as this fault is approached, and the fault itself has a more nearly north-and-south trend than the others of its class. The Black River limestone west of the fault is heaved 250 yards to the south, a greater lateral distance than the heave of H-H, but the dip is correspondingly less. A throw of about the same amount as that of H-H is thereby indicated, but in the reverse direction, the northeast being the thrown block. In other words, the

* Am. Geologist, November, 1888, p. 326.

† Geikie: Text-book of Geology, third edition, p. 553.

block between H-H and I-I is a wedge thrown down between the adjacent blocks to the north and south, these last being in substantial accord. Their continuity has not been affected by the faults, which have simply thrown down the intervening block.

*Fault K-K.*—At the extreme southeastern limit of the area shown on their map, Brainard and Seeley met and noted evidence of this dislocation. The testimony, as to its reality and position is of the same unequivocal character as that for the other faults, and, as the Black River limestone furnishes in every case the most convenient horizon for use in defining the fault, the corroborative evidence of other horizons may be omitted from the discussion. The Black River, south of the fault, lies 85 yards to the east of the same bed north, measured normal to the strike. This, together with the low dip, indicates only a slight throw for the fault—40 feet as a maximum, with the throw to the south.

### *SUMMARY OF THE FAULTS.*

From the preceding descriptions it may be seen that the assemblage of faults E to K, inclusive, are peculiar in certain respects. The zone lying between the great faults A and C is greatly shattered, not only absolutely, but also when compared with the rest of the area under discussion. The zone between faults B and C will answer best for comparsion. Though the work on that zone is somewhat incomplete, it is evident that it has suffered far less from faulting than the other. As has already been indicated, the disturbance around Chazy village is greater than can be displayed on a map of small scale. Witness the outcrops of Black River limestone along fault A-A between the Potsdam and the Chazy.*

Two possible explanations of the disturbed zone at Chazy village suggest themselves to the writer. One has already been hinted at, namely, that faults A-A and C-C form a sort of double fault, or, in other words, may be considered as one fault with a crushed zone of unusual width.†

The second explanation would perhaps be a more natural one. If the three faults A-A, B-B and C-C are prolonged northward, holding approximately the same trends, they may perhaps come together—that is, the three faults may have been formed by the subdivision of one fault. What seems a similar case is exhibited north of Plattsburgh, where the fault B-B separates into two branches, bringing up a wedge of Chazy between the Calciferous and Trenton.‡ This wedge is much shattered and broken in a manner quite similar to that in the region around Chazy. Brainard and Seeley's map of Providence island and the neighboring portion of South Hero seems to illustrate a similar case.§

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* See ante, p. 293. † See ante, p. 290. ‡ See ante, p. 290.

§ Bull. Am. Mus. Nat. Hist., vol. iii, no. 1, pp. 18, 21.

The faults of the third class may be characterized as minor breaks produced abundantly in narrow zones, either between two branches of a fault of the first class or else between two faults of that class which approach rather closely and seem related to each other. They are confined to the block between the two faults, being in that respect like the faults of the second class. They may perhaps be better regarded as a mere phase of the faults of that class, produced in unusual number under local circumstances.

### Other probable Faults.

The facts here set forth have been incidentally noted by the writer while engaged as assistant to Professor J. F. Kemp in mapping the areal geology of the region. The results are therefore incomplete, portions of the area requiring more detailed work than it has yet been found possible to bestow on them. There are indications of the presence of other faults than those here noted, this being more especially true of the southern part of the township, where the apparent great extent of the Calciferous and the lack of other formations implies a considerable amount of faulting. Some of the faults already mapped require further study for their proper elucidation. They are sufficiently well worked out, however, to answer the purpose for which the paper was written.

### Non-appearance of the Calciferous at Chazy Village.

The theory has been advanced that the Calciferous is lacking at Chazy village because of non-deposition.* As a result of their work in the vicinity, Brainard and Seeley maintained that the Calciferous might be thrown out by a fault along Tracy brook, that such a fault existed, and that the great disturbance of the rocks at Chazy village was the result of said faulting.† With the latter explanation the writer fully agrees and would urge in its favor that the present relations existing there between the Potsdam and Chazy are clearly the result of disturbance and give no clue whatever to their possible relations prior to the disturbance; that a great fault (A-A) separates the two, and is in itself sufficient to account for the absence of the Calciferous; that at the only locality in the township where the structure permits of the outcropping of the beds which lie beneath the Chazy the Calciferous appears; that both to the north and south within from two to four miles the Calciferous is present in such force that the warping necessary to produce the supposed cessation of deposition must have been local in the extreme, and finally

* C. D. Walcott: Bull. 30, U. S. Geol. Survey, p. 22.
† Am. Geologist, November, 1888, p. 327.

that in the township next south a precisely similar fault (B-B) hides the entire Chazy limestone from view throughout the township, though it reappears again in the next town beyond in the same strength which it exhibits in Chazy township.

## Conclusions.

In the rocks of Ordovician age occurring along lake Champlain the detection of faults is not a matter of great difficulty, but back from the lake in New York the criteria which avail for their determination in the Ordovician rocks are not furnished by the older Cambrian and pre-Cambrian strata.* Yet that both are much faulted is certain.

It has just been shown that a large proportion of the contacts between rocks of different age in Chazy township are fault-contacts, and the same may be shown with equal readiness in most other townships on either side of lake Champlain. It is believed that this will be found to be true also in the Adirondacks themselves, but their discrimination from ordinary deposition-contacts will be extremely difficult. As an illustration: Wherever in Clinton county the writer has found demonstrable deposition-contacts between the Potsdam and the older rocks a basal conglomerate or an arkose or both are shown. Where these are absent the relations are often such as to strongly suggest contact by faulting. At other times no indications whatever of the character of the contact are afforded. That the crystalline rocks of the Adirondacks are also faulted can be often shown by means of the numerous dikes and of the beds of iron ore. The topography is often such as to strongly suggest faulting. Certainly the possible presence of faults must be constantly kept in mind when endeavoring to interpret the stratigraphy of that region, and the main purpose of this paper is to emphasize this fact, in view of the work now being prosecuted there.

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* The term pre-Cambrian is preferred at present for these rocks, as it is purely non-committal.

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# HONEYCOMBED LIMESTONES IN LAKE HURON

BY ROBERT BELL

(*Read before the Society December 29, 1894*)

CONTENTS



## AREA OF OCCURRENCE AND CONDITIONS.

The limestones in the bottom of a certain portion of lake Huron are undergoing a peculiar kind of erosion, which, from want of better terms to describe the process, may be called honeycombing and pitting.

The portion of the lake in which this phenomenon is most prevalent is that around Grand Manitoulin island, the Indian peninsula and in Big gap, which lies between them and connects the main body of the lake with Georgian bay. This curious form of erosion appears to be progressing most rapidly under a considerable depth of water, say, from 50 or 100 feet, down to greater depths, but it may also be going on in shallower water. The existence of the honeycombed limestone all over the bottom of this part of lake Huron is well known to every one living in the vicinity, and especially to the fishermen, to whom it is a great source of annoyance from their nets catching upon it. Visitors carry away specimens of it every summer as curiosities, but, so far as the writer is aware, no one has yet described its occurrence, attempted to explain its cause, or reported a similar condition elsewhere. The phenomenon therefore appears to be rare, if not unique, and worthy of a description from a geologic standpoint.

Grand Manitoulin island is 80 miles in length. Along its southern side the undisturbed Silurian limestones slope very gently southward under the lake, so that shallow water extends a considerable distance from shore. On surfaces which have been long exposed to the weather or to the wearing action of the waves the pitting is more or less effaced, but wherever they have been covered by the water or otherwise sheltered it is still plainly visible. In the autumn the whitefish come into shallow water to spawn, and the fishermen say that the rough limestone bottom, here described, is a favorite resort for this purpose. As its inequalities protect the eggs from destructive currents and predaceous fishes, it may be said to serve an economic purpose.

## Physical Characteristics of the eroded Rocks.

Various kinds of limestones have been acted upon by this peculiar form of erosion. The unaltered varieties have been completely riddled with cavities, varying from very small holes up to three inches or more in diameter, the average being between half an inch and an inch, but in altered or crystalline limestones or dolomites the pits are mostly larger and shallower. The pitting of these rocks will be more fully noticed further on. In unaltered dolomites one form assumed by the cavities is globular to pear-shaped, and in the process of enlargement they encroach upon one another until only thin walls remain between them, while others coalesce, and ultimately the whole mass becomes separated into a highly eroded skeleton, as shown in figures 1 and 2, plate 13, taken from photographs. Even in this stage, the solid angles between adjacent cavities become perforated by smaller holes, and at length the rock crumbles to fragments, with deeply hollowed concave surfaces. The removal of such a wasted exterior exposes a pitted surface on the next lower layer of limestone, the contiguous cup-shaped hollows usually occupying the whole area. A completely sculptured surface resembling this may also be produced by the direct solvent action of the water without the intervention of the globular honeycombing. Large areas showing surfaces of this kind, which had been eroded at a considerable depth, may now be seen in the clear, shallow water or exposed to the air, owing to the lowering of the level of the lake, while wide borders of nearly horizontal limestone beds, similarly eroded, are exposed in some localities between the margin of the water and the wooded shore. These extremely eroded surfaces have a striking appearance, and the sharp and pointed edges of the pits would be painful to walk on without thick soled boots.

Another form which these cavities take is finger-shaped, crowded together and deeply indented, or of such a shape as would be completely filled by inserting the sharp end of a cigar. As in the other forms, the cavities at their tops adjoin each other, leaving no space between them.

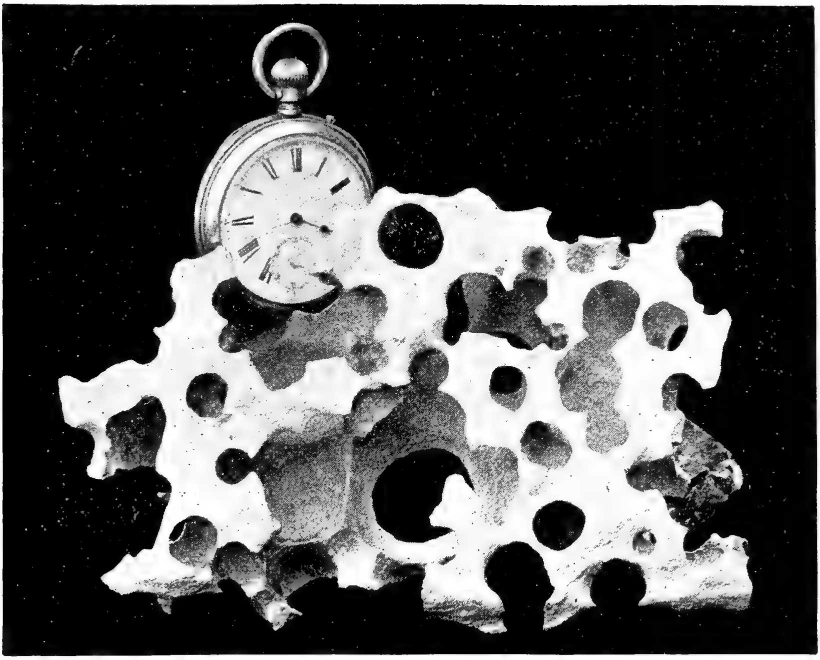

FIGURE 1.—VIEW AT A RIGHT ANGLE TO THE BED-PLANE.

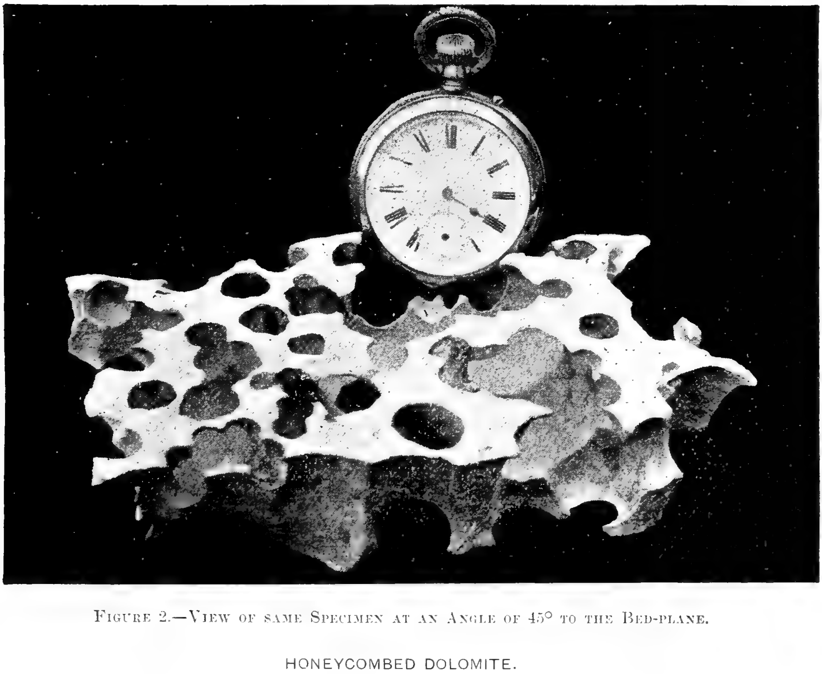

FIGURE 2.—VIEW OF SAME SPECIMEN AT AN ANGLE OF 45° TO THE BED-PLANE.

HONEYCOMBED DOLOMITE.

From South Bay Mouth, Manatoulin Island, Ontario, Canada.

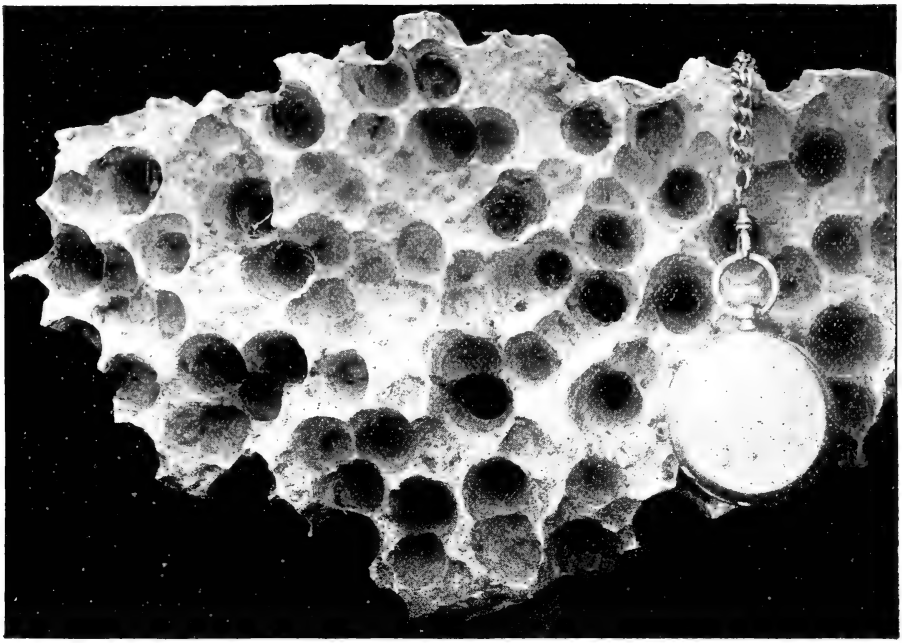

Figure 1.—View of under Surface at a right Angle to the Bed-plane.

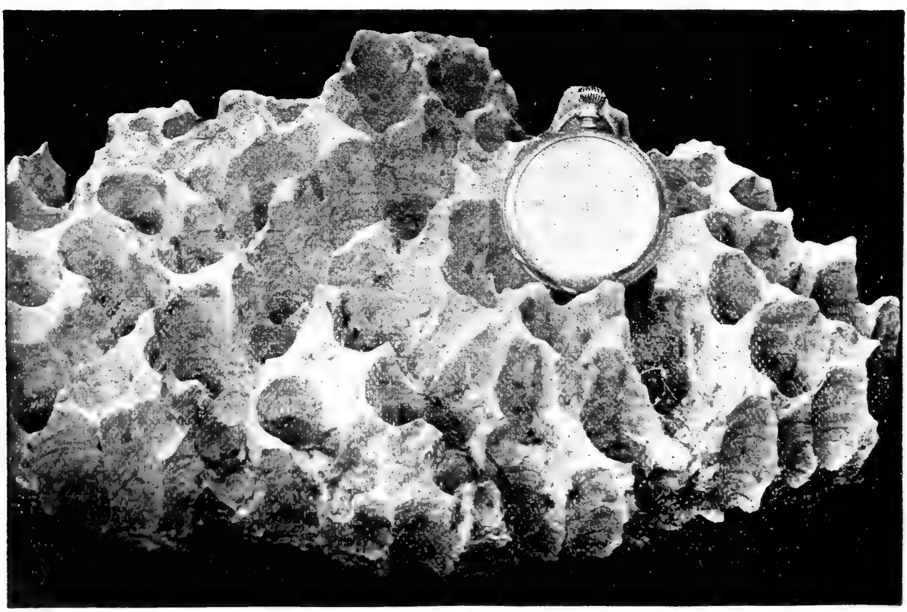

Figure 2.—View of same Specimen at an Angle of 45° to the Bed-plane.

PITTED LIMESTONE OF THE BLACK RIVER FORMATION.

From Little Cloche Island, Ontario, Canada.

This variety of deeply pitted surface resembles limestone which has been thoroughly riddled by the burrows of *Saxicava*. In a well marked case, to be again noticed, where a submerged shelf or hanging ledge was eroded on the under side, the pitting took the form here described. It is well shown in figures 1 and 2, plate 14.

### Age and Attitude of the eroded Rocks.

The rocks of Grand Manitoulin and the adjacent islands embrace eight different formations, from the Chazy, in the northern part of the La Cloche island, to the Guelph, on Fitzwilliam island and on the southeastern part of the main island, while dolomites of the Huronian system are met with on many of the islands of the channel between the Manitoulin chain and the main north shore of lake Huron. The Chazy is represented by brownish red and green marls and fine grained white sandstone; the Black River consists of pure limestone and yellow weathering dolomites; the Trenton principally of bluish gray limestone, with earthy beds; the Utica of black bituminous shale; the Hudson River of marls, with thin beds of limestone and sandstone; the Clinton of dolomite, with bright red and green marls at the base, while the Niagara and Guelph formations are composed almost entirely of dolomites. The dip is uniformly to the south, at a very low angle, and the naked beds of the higher formations above enumerated slope gently under the lake along the southern sides of all the islands of the Manitoulin group.

### Erosion Forms in Relation to Variety of Rock.

The largest and most irregular cavities are in the magnesian limestones of the Guelph formation. Their appearance *in situ* is shown in plate 15, which is from a photograph. The globular and pear-shaped varieties, shown in figures 1 and 2, plate 13, are excavated in somewhat argillaceous dolomites of the Niagara and Clinton formations. The cup-shaped hollows are commonest in the pure limestones of the Hudson River, Trenton and Black River and in the dolomites of the last mentioned formation. The finger-shaped honeycombed structure was found principally in the pure limestone of the Black River formation, while the smoother and rather larger excavations are characteristic of the Huronian dolomites. The shallower varieties of this form of pitting resemble that of a well eroded aërolite. The occurrence of these various forms of honeycombing and pitting in such a variety of limestones and dolomites in this portion of lake Huron proves that the phenomenon is not due to anything unusual in the general composition or to any chemical peculiarity of a particular variety of rock, but to some outside cause. The various forms which the erosion takes, however, show a slightly unequal solubility connected in some way with the internal structure of the rock;

otherwise it would be of a more uniform character, since it is due to some common external cause operating alike upon them all.

The dissolving of the unaltered limestones or dolomites goes on at right angles to the bedding or directly downward or upward, as the rocks are practically horizontal, never at an oblique angle nor horizontally, which, in the absence of some inhibiting cause, might easily take place in loose masses which lie at all angles on the bottom of the lake. On isolated blocks, where the sides have been as freely exposed to the water as the top, the solvent process appears to prefer to work downward from the "quarry bed" and not to eat inward from the sides.

Experiments made by Professor Goodwin, of Queen's University, Kingston, on the action of solvents on slowly soluble substances seem to show that the tendency of solution is strongest directly upward and downward. This, together with a faint concretionary structure, to be noticed further on, may help to account for these forms of erosion.

Allusion has been made to a well marked case, where the pitting has progressed directly upward from the under surfaces of beds of pure limestone forming the roof of an overhanging ledge or shelf which had been submerged when the lake was a little higher than it is at present. This occurs along the east side of The Narrows between Little Cloche island and the southern part of Cloche peninsula. The rock, which belongs to the Black River formation, consists of a soft bluish grey limestone containing a little argillaceous matter. The tapering finger-shaped pits are closely crowded together and they penetrate upwards from two to four inches from the general outline of the roof. Silicified fossils project from the walls into these pits, and when the rock is broken across a discoloration of iron oxide is seen to extend a short distance all round the wall of each one. Plate 14 illustrates these pits.

## Possible Origins of the Erosion.

### *BORINGS OF MOLLUSKS.*

The writer may not have arrived at a correct explanation of these curious forms of erosion, but he will endeavor to state the suggestions which have occurred to him in regard to their origin, along with a description of the circumstances connected therewith. Many theories to account for these phenomena may present themselves both to those who have and those who have not seen them on the ground, and it may be as well here to notice briefly the more obvious ones.

Cavities resembling some of those above described are made in rocks by boring mollusks, such as *Saxicava*, *Pholas*, *Petricola*, *Callista*, *Tapes*, *Venerupis* and *Lithodomus*. The case of the zones on the marble pillars of the temple of Jupiter Serapis, at Puzzuoli, eroded by lithodomi,

GLACIATED AND HONEYCOMBED DOLOMITE OF THE GUELPH FORMATION.

South Bay Mouth, Manitoulin Island, Ontario, Canada.

which has been rendered classic by Lyell in his "Principles of Geology," will occur to every geologist. The cavities formed by boring mollusks are, however, burrows which are of pretty uniform calibre, or increase in diameter with the depth, owing to the growth of the animal as it proceeds. They are generally many times deeper than wide, whereas those under consideration are either globular or short by comparison, and they contract instead of enlarge toward the bottom.

### *ACTION OF SPONGES AND ALGÆ.*

A small sponge, *Cliona celata*, makes burrows in the shells of oysters, and this fact led to the supposition that possibly some species of fresh-water sponge might have aided in deepening or enlarging the cavities under discussion, or in determining their form by the production of small quantities of an organic acid, either during life or upon decomposition, but no evidence could be found in support of this idea. The remains of branching fresh-water algæ may be seen in some of the cavities, but they do not appear to have exercised the least influence in their production. The lower or jelly-like algæ of fresh water do, however, possess the power of dissolving limestone. The journal of the Royal Microscopical Society for October, 1894, says, on page 597, that—

> "Professor F. Cohn points out the important part played by very lowly organized algæ—Phycochromaceæ and Cyanophyceæ—in the formation of calcareous and silicious rocks. Many beds of marble and travertine have been formed in this way. He further enumerates the algæ that are known to destroy calcareous rocks by erosion. In all fixed algæ there appears to be this contrast between the basal cells and the rest of the filament; that the former excrete an acid which dissolves lime, while the latter has the power of depositing a soluble lime-salt between the filaments, but within the mucilage which is excreted from the sheath."

### *WEARING ACTION OF PEBBLES.*

A popular notion current among many of the residents of the localities where the pitted surfaces occur is that the cavities have been worn by the whirling of pebbles and sand in a manner analogous to the formation of potholes at rapids and falls. That they have not been thus formed is obvious from the following reasons, selected from among others:

Their shapes do not correspond with this mode of formation.

They occupy the whole surface of the rock, whereas potholes occur at irregular intervals.

The walls of the cavities are generally uneven or rough, and delicate silicified fossils often project from them or stretch completely across the cavities, whereas the wearing action of rotating pebbles and sand would have produced smooth and cylindrical walls.

No pebbles are ever found in them except such as can be shown to have been placed there subsequent to their excavation. If these cavities

had been due to this cause, their occurrence would not be confined to the limestones of lake Huron, but would be a general phenomenon in connection with similar rocks all over the world. On the contrary, the pebble theory is not sustained by facts anywhere. Pebbles washed by currents passing over rocks or grated against them by the waves, not only do not pit or honeycomb rocks, but they have the opposite effect and wear them smooth.

It is true that gravel may now be seen scattered over local pitted surfaces which have been laid bare by the recession of the lake, but on examining cases of this kind it is always manifest that the gravel was placed upon such surfaces long after the completion of the pitting.

The occurrence of the cavities equally on the tops of loose blocks of limestone and on the solid beds is another objection to this theory.

A final objection is the fact that some of the most beautiful examples of deep pitting are found on the under surfaces of overhanging beds, the eroding agent having worked upward in a free body of water.

### Acid Water the probable Cause of the Erosion.

Having eliminated all the possible causes which have suggested themselves as being unlikely to have produced the erosion under discussion, the question arises: To what must we attribute it? It appears most probable that the cause will be found in the differential solubility of the rock in the water of the lake itself. The slight difference in the solubility of those parts of the rock which give rise to the cavities is likely due to its internal structure, which originated, in the first place, at the time of the formation of the limestones or dolomites themselves. The eroded beds are not generally those which are largely made up of organic remains, but oftener those which have been due to chemical precipitation. There are, however, exceptions to this general rule which add to the difficulty of accounting for this singular phenomenon. In the process of consolidation of chemically formed beds in which lime, magnesia and argillaceous matters were present, there would naturally be more or less tendency to concretionary action around certain points or centers, thus giving rise to slight differences in composition. Even if such concretionary structure were too obscure to be readily noticed, the probability of its existence in the rocks of the above composition will be readily admitted; but in some cases, especially where oxide of iron is present, this structure may be detected in the form of obscure concentric lines. The globular shape of the cavities is a fact which points to this origin. But, if this be true, it may be asked, why are similar limestones not always eroded in this manner when they are covered by fresh water? The explanation of the difference is probably to be found in a sufficiently acid condition of the water of this part of the lake to slowly dissolve the limestones.

The solvent action of the slightly acidulated water is, no doubt, aided by certain conditions favorable to it in the present case, but which might be absent elsewhere, even if the requisite amount of acidity existed. The water of this part of lake Huron is perfectly limpid and free from suspended impurities, so that there is nothing to check the progress of the dissolving process, no matter how slowly it may be going on. That it has been exceedingly slow in its operation is shown by the pitted or honeycombed surfaces retaining their glaciated forms. As the basin of lake Huron has no doubt been filled with water since the disappearance of the ice-sheet, the time required for the erosion under consideration must have been many thousands of years, but the proportion of acid in the water probably increased gradually, as the explanation to follow will show.

### Sulphuric Acid in the Water and its Source.

Although the water of this part of lake Huron has not been analyzed, it appears to contain a notable proportion of sulphuric acid. It has the property of slowly reddening vegetable matter, purple or blue. Its corroding action on tin pails and pans is a source of annoyance and loss to housekeepers and campers who use the water for domestic purposes. A new tin pail, if kept filled with the lake-water, will in a few days show rusty excrescences in the bottom, which increase rapidly and soon perforate the vessel. The water of the portion of the lake where honeycombing of limestones is most obvious is distinctly harder than elsewhere, probably owing to the pressure of sulphate of lime.

The source of the sulphuric acid may be looked for in the Huronian rocks lying to the northward of the lake. It is remarkable that the portion of the lake in which this form of erosion of limestone takes place lies directly in front of that part of the north shore occupied by the Huronian rocks, and receives several considerable rivers which drain an immense area of rocks of the same age. They are mostly of volcanic origin and are rich in sulphides, whereas all the other rocks around the lake are comparatively free from them.

Sulphides of several metals, but especially of iron, are disseminated through most of the Huronian rocks. Pyrites and pyrrhotite are particularly abundant in the greenstones, and these form a considerable proportion of the series. The two sulphides referred to occur both as disseminated grains and in the form of numerous masses, some quite large, such as those around Sudbury, a few of which are being worked for nickel. The decomposition of these sulphides upon the surface of the rocks and along their fissures and joints produces iron-sulphate, which is carried away by the streams, where its presence is frequently shown by the precipitation of a part of the iron. In the swamp at the Murray mine near Sudbury, where a large mass of pyrrhotite and chal-

copyrite comes to the surface, the presence of acid sulphate could be detected by the taste of the water, and when the latter, containing as it does vegetable matter also, was used experimentally for the boilers, it gave off a most offensive smell and had a very corrosive effect. The streams of the whole of this Huronian region no doubt receive many contributions of acidulated water from similar sources. As the decomposition of the greenstones and other pyritiferous rocks, and also the oxidation of the drift materials derived from them, proceeds, the quantity of acid derived from them and carried into the northern part of lake Huron will increase. At The Narrows between Cloche peninsula and Little Cloche island, as already mentioned, the pits in the soft argillaceous grey limestone are surrounded by a zone stained by iron oxide. This is just what might be expected to result if such a rock were being slowly dissolved by iron-sulphate and, therefore, this fact helps to support the present hypothesis.

The fresh rock-surfaces and unoxidized drift left at the close of the Glacial epoch would produce a much smaller proportion of sulphuric acid in a given time, and we therefore suppose that the erosion of the limestones in the bottom of the northern part of lake Huron went on even more slowly then than now.

Another example may be cited here of water containing sulphuric acid which has been derived apparently from volcanic rocks. A sample from the shallow fresh-water in the estuary of the Nelson river, Hudson bay, was taken by the writer to the late Professor William Dittmar, the well known authority on water analyses, and he found it to contain no less than 4.73 grains of sulphuric acid to the imperial gallon.* The source of this acid appeared to be the drift-material which had come from the volcanic rocks of the central or eastern part of the bay.

## Conclusions.

The conditions which have contributed to the production of the peculiar forms of erosion above described appear to have been:

1. The internal structure of the limestone itself.
2. A small quantity of acid in the water acting for a great length of time.
3. A considerable depth of water, the hydrostatic pressure seeming to promote the dissolving of the rock.
4. Freedom from sediment during the long time required.
5. The rock must be exposed to the open or free action of the water.
6. Shifting currents in the water would also appear to assist the process.

*See Appendix V, Report C, of the Canadian Geological Survey for 1879–'80, p. 78.

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# THE POTTSVILLE SERIES ALONG NEW RIVER, WEST VIRGINIA

BY DAVID WHITE

(*Read before the Society December 28, 1894*)

CONTENTS



## INTRODUCTION.

This paper is intended to present certain general conclusions reached in the course of a preliminary study of the stratigraphy and paleontology of the Pottsville series along New river in West Virginia. While concerned mainly with paleontologic correlations, it touches incidentally

on the stratigraphic position of the well-known New River coals mined at numerous points from Quinnimont down to Hawks Nest.

## Use of term "Pottsville" and Formations included in "Pottsville Series."

The Pottsville series, or the "Conglomerate series," as it is perhaps better known in West Virginia, embraces the group of sandstones, conglomerates, sandy shales and coals lying between the green and red calcareous Mauch Chunk shales below, and the softer, more argillaceous terranes of the "Lower Productive Coal Measures" above. It is essentially a sandstone series, though it includes some of the most valuable soft coals of the Appalachian region. Its massive ledges, rising often abruptly at short intervals from one another, support a more or less clearly defined terrace plateau, across which for more than 30 miles the river has cut its celebrated gorge. The outcrop of the series is conformable to the general Appalachian trend. It is fringed on the east by certain high knobs northeast of Hinton, and it descends westward to the falls of the Kanawha, below which it passes under water level.

The general characters of the group in southern West Virginia have been well described by Professors W. M. Fontaine* and I. C. White.† To the New River section the former gave the name "Conglomerate series," so defining it as to include the lowest and the uppermost conglomerates in the Piney Creek section, he supposing the uppermost to represent the Kanawha Falls sandstone. Fontaine's Conglomerate series was in large part referred by Professor White to the "Pottsville," both authors regarding it as the equivalent of the Pottsville conglomerate, the lower boundary being drawn by the latter author at the top of the red and green shales. The reference of the entire series to the Pottsville has been made, so far as I know, almost wholly on the basis of the stratigraphic evidence, the facts being, first, that it is more or less distinctly conglomeratic, and, second, that it occupies the interval between the Lower Carboniferous marine beds and the true Lower Productive Coal Measures (XIII of the Pennsylvania geologists) of the Appalachian basin.

## Purpose of this Study.

The present paper will necessarily be limited to a few somewhat generalized conclusions, resulting from a preliminary paleontologic and

* The Great Conglomerate on New River, West Virginia. Am. Jour. Sci., third series, vol. vii, 1874, pp. 459, 573. The Conglomerate Series of West Virginia. Am. Jour. Sci., third series, vol. xi, 1876, pp. 276, 374.

† Bull. U. S. Geological Survey, no. 65, 1888, p. 179 et seq.

stratigraphic examination of the New River section, made in order to ascertain the general relations of the major divisions of the series there, together with the contained coals, to the Pottsville series in other portions of the eastern Carboniferous basins, as well as to establish a paleontologic section for comparison of local floras in the central portion of the Appalachian region. Although the work on the section is not yet completed, it is thought the facts ascertained are of sufficient interest to justify a preliminary publication.

So far as the discussion concerns other regions, the evidence considered will be mostly paleontologic and therefore chronologic.

## Rapid Differentiation of and Change in Floras during Pottsville Time.

It should be remarked at the outset that wherever plants have been gathered from several horizons in thick sections of the Pottsville in different portions of the Appalachian belt, a careful scrutiny of the specimens shows a distinctly notable difference between the floras gathered at intervals of several hundred feet in the same section. Indeed, the period of change in conditions of environment attending the transition from Lower Carboniferous marine to true Coal Measures formation was marked by an extraordinarily rapid development and modification of vegetable species. Within a relatively short period the meager flora of the Devonian and Pocono is multiplied to the inexhaustibly fecund and highly diversified flora of the Carboniferous, a development scarcely possible except in this division of organic life, which is the most sensitive to climatic change or environment, excepting perhaps the higher vertebrates. In the lower part of the Pottsville series many species show a relation to the floras of the Vespertine or Calciferous Sandstone series; in the middle portion many of the forms are unique, while in thickly developed sections it is only near the top of the series that we see occasional Coal Measures forms creeping in.

These modifications and differentiations of forms have been found to be fairly consistent and generally constant in their relative position in the various sections thus far examined. This is true even of those very distant, but because the modification of a plant from one stage to another, though representing a definite phase or form, is often not sufficient to constitute a distinct species, and because these stratigraphic modifications of species have received little or no attention in our American literature on Paleozoic plants, I shall frequently be obliged to refer to them as forms, designating them by the name of some locality or well

established horizon in which they have so far been characteristically or predominantly found.

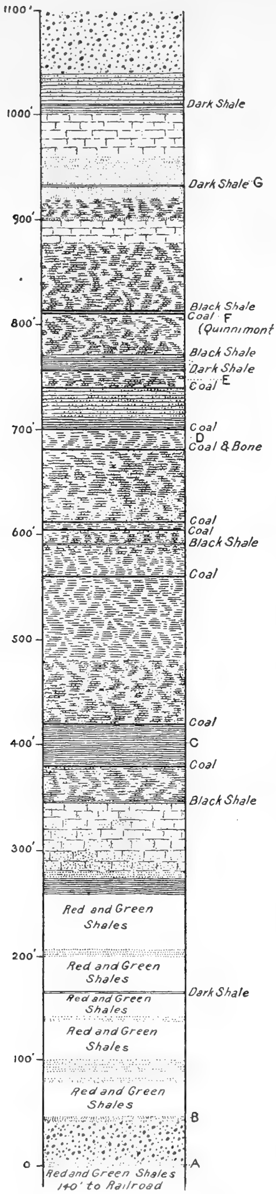


FIGURE 1.—*Piney Creek Section.*

## STRATIGRAPHY OF THE SERIES.

### *GENERAL STATEMENT.*

Before introducing any paleontologic facts it will be necessary to present their proper stratigraphic setting. Accordingly, while it is not my province to discuss the stratigraphic equivalents of the individual beds in other Appalachian sections, I give here two sections which show the series as a whole, the position of the mined coals and the beds from which plants were obtained.

### *CONGLOMERATES OF PINEY CREEK SECTION.*

The first section (see figure 1), that along the road up Piney creek, about two and one-half miles below Princes station on the Chesapeake and Ohio railroad (chosen because it is the type section described by Professor Fontaine), is one of the most complete along the river, though badly weathered, and consequently appearing much less arenaceous than other sections up the walls of the gorge.

The two conspicuous bench marks of the sections along this portion of the river are the massive conglomeratic sandstones at the top and near the base of the declivity. The lower one, frequently more or less calcareous, is a conspicuous feature of the gorge of New river in the vicinity of Mill creek, Quinnimont and Princes, where enormous blocks, which at first sight resemble those so abundant in the neighborhood of Nuttall and Fayette, have fallen into the river. Although the calcareous red and green shales extend nearly 200 feet higher up, this lower conglomerate was made the base of the "Conglomerate series" as originally defined by Professor Fontaine. Though almost without partings in the region of Piney creek, it loses much of its massive conglomeratic individuality in passing down the river, where it becomes hardly distinguishable from

other more or less conglomeratic sandstones at various horizons higher in the series. Largely to this fact, as well as to the irregularity and instability of the lower sandstones of the various sections and to a slight undulation of the strata, are probably due the differences of opinion still current respecting the number and equivalence of the coals worked along New river.

The upper member of the Piney Creek section, another massive conglomeratic sandstone, is now known to be quite distinct from the remarkable formation at the top of the Nuttall section correlated with the Homewood sandstone of Pennsylvania by Professor I. C. White. With the exception of the latter, this top Piney Creek sandstone is the most regular and persistent member of the entire series in this region, though its conglomeratic habit is somewhat variable. I have traced it quite clearly in more than twenty-five sections from Crow, about 9 miles southwest of Quinnimont, to near water level at Hawks Nest, where it forms the foundations for the railroad bridge across the river. Its massive conglomeratic ledge is the "table rock" at Table Rock post-office and defines the brow of the terrace plateau and river gorge for most of the distance down to Fire Creek. From its crest above Fire Creek mine there opens a superb vista of the gorge and terrace, extending to the northward, in which near Keeneys creek and Nuttall the "Homewood," about 400 feet higher, is seen to descend to complete the wall of Pottsville rocks which gradually declines to the falls of the Kanawha.

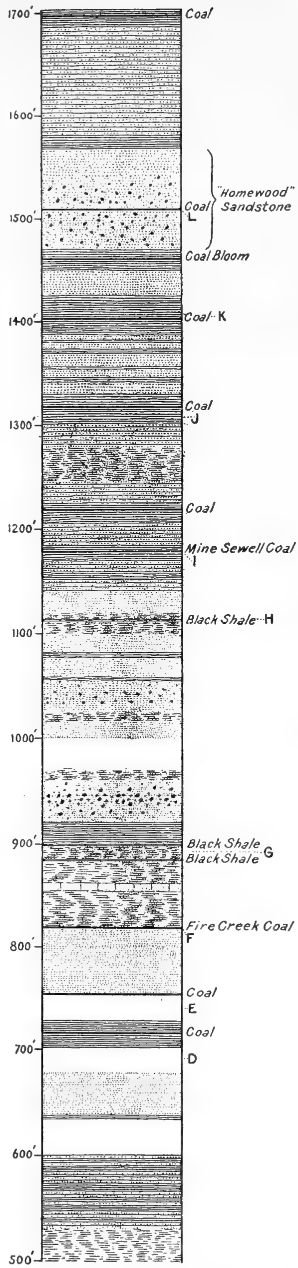

FIGURE 2.—*Nuttall and Hawks Nest Section.*

*COMPLETION OF SERIES AT NUTTALL AND HAWKS NEST.*

The continuation of the Piney Creek section up to the base of the "Homewood sandstone" is given (see figure 2)* from the Nuttall sec-

*The accompanying sections are platted from the barometric readings at the specified localities.

tion, which I have chosen because the series in this vicinity has been selected for description by Professor I. C. White.*

The features of the "Homewood," which completes the Pottsville series, and the superimposed basal portion of the Lower Productive Coal Measures I have taken from the section at Hawks Nest.

The examination of a number of measurements indicates the thickness of the Pottsville series along New river to be approximately 1,600 feet, if we measure from the base of the lower conglomerate on Piney creek, the base of Professor Fontaine's "Conglomerate series," to the top of the Homewood, or about 1,300 feet if we follow Professor White in measuring from the top of the red and green shales, a result which agrees in the main with that published by the latter author.

### *NUMBER AND POSITION OF COALS MINED ON NEW RIVER.*

A comparison of the sections, which were made at nearly every mine above Sewell, shows almost conclusively that along New river only two seams are mined in the Pottsville series. In fact, instead of finding that the operations cover two or three veins below the upper Piney Creek conglomerate, as has commonly been supposed, all the openings appear to be at the same horizon and in the same stratigraphic sequence—the Quinnimont coal being the same as the Fire Creek coal.

Although my sections of the series are barometric and were sometimes made under unfavorable conditions, they cover so many localities within a distance of about thirty miles along the river, and they are so remarkably harmonious in showing that the workable coals fall so closely within the same limits, as to establish a probability, so strong as to justify the assumption as a working hypothesis at least, that all the mines below the upper Piney Creek conglomerate are in the Quinnimont-Fire Creek seam, the mines between that conglomerate and the Homewood being confined to the Sewell coal.†

### *QUINNIMONT-FIRE CREEK HORIZON.*

In the Piney Creek section (see figure 1) I have marked as "Quinnimont" a coal having precisely the same position and local characters as that found in the mines on the Quinnimont seam in that vicinity. Its distance from the top of the upper Piney Creek conglomerate in this case is the same as that measured on Mill creek, at Quinnimont and Alaska, the stratigraphic association being exactly that at the Royal mine, near

* Bull. U. S. Geol. Survey, no. 65, p. 197.

† So close, if not identical, are the Quinnimont and Fire Creek coals that a number of leveled sections will be required to fully establish their relations. Considering the circumstances of exposure and existing developments it seems improbable that two workable coals should be so close together in one section of this region without the discovery of both in the same section.

Princes, two and one-half miles above. If my barometric sections are not erroneous, the same seam is worked at Beechwood, Stone Cliff (lower opening), Dimmock, Rush Run, Red Ash, Beurys and Fire Creek. Thus at the last named mines, which admittedly work the Fire Creek coal, the interval from the mine mouth to the top of the upper Piney Creek conglomerate falls within the same limits, approximately 295 feet, while the stratigraphic environment is the same as at Quinnimont, Princes and other mines unquestionably working the Quinnimont coal.

Among New River coals, as well as among Pottsville coals in other regions, there is much variation in the roof and in the thickness of the seams themselves. At Quinnimont and Mill creek good fossils are extremely rare; at Princes, Alaska, Fire Creek and Beurys a few fragments were obtained, while Stone Cliff and Red Ash approach the rich flora found at Dimmock and Rush Run. The increasing richness of the flora toward the apex of the long bend of the river near Thurmond suggests a better preservation of the plant remains toward the northwest or down the dip, though the latter circumstance may be merely coincident.

### *POSITION OF SEWELL COAL.*

Measuring again from the top of that valuable bench mark, the upper Piney Creek conglomerate, my barometric readings show the mine mouths at Thurmond, Brooklyn opposite East Sewell, Cunard opposite Sewell, Nuttall, Fayette, Elmo and Hawks Nest to fall within a distance of from 55 to 85 feet, or approximately 75 feet. There is little room for doubt that the mines at these points are all in the same seam, best known as the "Sewell" or "Nuttall" coal. This coal (see *I* of figure 2) is also exposed at Rush Run, about 70 feet above the upper Piney Creek conglomerate, or 365 feet above the opening on the Quinnimont-Fire Creek coal. The same seam is reached by tram in the knob back of Beurys, and again by the same method farther up the river, at Stone Cliff. Although no sections were made at the following points, it appears very probable that the mines at Slaters and Central are in the Quinnimont-Fire Creek coal, the operations at Caperton, Keeneys Creek, Gaymont and Sunnyside being in the Sewell coal. Dr D. W. Langdon, whose geologic interpretations are well known to be reliable and who is especially familiar with the New River series, kindly informs me that the Loup Creek coal mines operate in the Sewell coal, a correlation with which the evidence of the fossils is quite harmonious.

From what has been stated above it appears that all the New River (Pottsville) coals now mined in this region come from two horizons—the Quinnimont-Fire Creek horizon and the Sewell coal.

As indicating in a general way the direction of the strike, it may be

noted that the coal outcrop and the upper Piney Creek conglomerate are respectively at nearly the same distance, barometric readings, above the Chesapeake and Ohio Railroad at Stone Cliff and at a point a little to the east of Beurys; so also at Rush Run and Cunard; or at the Thurmond mine and a point probably between Nuttall and Keeneys creek.

## Paleontologic Relations.

### GENERAL STATEMENT.

The general affinity of the plants collected by Professor Fontaine from the New River coals with those in the Sharon coal of Ohio has already been stated by Professors Fontaine and White. A portion of the material listed below comes from one or two of the former author's localities.

A preliminary examination of a collection recently made in the typical section of the Pottsville in the southern anthracite field of Pennsylvania and a comparison of it with that from New river shows that the floras are essentially the same, they being largely identical in the corresponding portions of the sections. In other words, the plants found in the greater portion of the "Conglomerate series" on New river are Pottsville plants and belong to stages represented in the Pottsville section of Pennsylvania. I have found the same to be true of the Great Flat Top Mountain and Tug River sections farther south.

### FOSSILIFEROUS HORIZONS.

Before proceeding further it is best to pass briefly over the localities from which plants were obtained, referring at the same time to the stratigraphic position of the fossiliferous beds in the accompanying figures.

The lowest beds from which plants were gathered are the strata immediately above and below the Piney Creek conglomerate, comprising the base of Professor Fontaine's "Conglomerate series" (see *A* and *B*, figure 1). Scanty material was gathered from these beds on Piney creek. Numerous fragments, poor in species, were gathered from or near an horizon about 370 feet above this conglomerate on Piney creek, at the mouth of Arbuckle creek, and near Rush Run (see *C*, figure 1). Specimens were collected at from 60 to 100 feet below the Quinnimont-Fire Creek coal on Mill creek, Piney creek (see *D* and *E*, figure 1), and at Nuttall (see *D* and *E*, figure 2). The Quinnimont-Fire Creek coal plants came from Quinnimont, Princes, Alaska, Beechwood, Stone Cliff, Dimmock, Rush Run, Beurys, Red Ash, Fire Creek (see *F*, figure 1), and Nuttall (see *F*, figure 2). Fossils were gathered at an horizon, about 100 feet higher, at Crow post-office, on Mill creek, and on Loup creek (see *G*, figure 1), and at Nuttall (see *G*, figure 2). Above the upper Piney Creek conglomerate

and below the Sewell coal fossils were found at Turkey Knob and Hawks Nest. From the Sewell coal plants were collected at Stone Cliff, Turkey Knob, MacDonald, Thurmond, Brooklyn, Cunard, Nuttall and Hawks Nest (see *I*, figure 2). Plants were found at several horizons between the Sewell or Nuttall coal and the base of the "Homewood sandstone" at Nuttall and Hawks Nest (see *J* and *K*, figure 2). At the last named locality a little material was dug from a parting in the Homewood itself (see *L*, figure 2). These were the highest plants collected from the Pottsville series. Some material was obtained from a coal in the Lower Productive Coal Measures, or "Alleghany series" of I. C. White, a short distance above the Homewood sandstone.

### *FOSSIL PLANTS NEAR THE LOWER CONGLOMERATE ON PINEY CREEK.*

As it is not my purpose in this paper to attempt any local or detailed paleontologic correlations, I shall consider only the plants obtained from a few of the richer or more interesting horizons.

The identifications are preliminary, and many of the names, for reasons stated at the beginning, are, pending revision or description, merely tentative and subject to change.

The shales immediately above and below the lower Piney Creek conglomerate, which, like portions of the conglomerate itself, are more or less calcareous, are poor in plants. From those at the base (see *A*, figure 1) I obtained:

*Sphenopteris subgeniculata*, (Stur.) Schütze (?).
*Sphenopteris* cf. *decomposita*, Kidst.
*Asterophyllites*, sp. indet.

*Sphenopteris subgeniculata* is one of the European Culm species, while *S. decomposita* is found in the Calciferous Sandstone series of Scotland.

From immediately above this conglomerate (see *B*, figure 1) were obtained:

*Adiantites*, sp. smaller than *antiquus*, (Ett.) Stur.
*Sphenopteris*, sp. extremely lax.
*Sphenopteris distans*, Stb.
*Asterophyllites* cf. *minutus*, Andr.
*Carpolithes*, small.
*Rhabdocarpus*, n. sp.

Here again those acquainted with Paleozoic fossil plants will recognize a general Lower Carboniferous cast, though the forms are few. *Sphenopteris distans* is a true Culm species, being one of the characteristic plants of the Hainichen-Ebersdorf Culm and the roofing-slates of Moravian Silesia.

About 150 feet of largely calcareous red and green shale and sand-

stones overlie the lower conglomerate, all of which are excluded from the "Pottsville" as restricted on New river by Professor I. C. White. In connection with this fact it may be noted that, while on New river the transition from marine to coal measures sedimentation is very much more gradual than in the Pottsville basin in Pennsylvania, it is marked by a much stronger contrast and evidence of change than is apparent in the Great Flat Top Mountain section. This section, while nearly destitute of conglomeratic material, presents an essentially arenaceous and quite frequently phytiferous series, with occasional coaly layers, as far down perhaps, if there is no unconformability, as the horizon of this lower Piney Creek conglomerate. This circumstance will be referred to later in relation to certain Appalachian evidence tending to show that the base of the Pottsville series (lithological) diagonals in time.

### *POCAHONTAS COAL ON NEW RIVER.*

One of the most interesting stages in the New River section is the next higher level at which plants were found. In shales associated with a thin coal (see *C*, figure 1) nearly 700 feet below the top of the upper Piney Creek conglomerate, or about 400 feet below the Quinnimont coal, a few species are common at Piney creek, at the mouth of Arbuckle creek, and near Rush Run. They are the following:

*Sphenopteris*, n. sp., Pocahontas form.
*Neuropteris smithsii*, Lx., Pocahontas form.
*Rhabdocarpus*, sp., Pocahontas form.
*Alethopteris*, sp.

The fact that the first three of these are predominant in and characteristic of the Pocahontas coal in Great Flat Top mountain and have not been found to extend far above or below that horizon led me to regard this stage, from paleontologic evidence, as equivalent or near to the Pocahontas coal, an opinion which has since been corroborated on the stratigraphic side by Mr M. R. Campbell, who has traced the strata from Tug river, about 60 miles away, across to New river.

### *FLORA OF THE QUINNIMONT-FIRE CREEK STAGE AND ITS AFFINITIES.*

Without stopping at this time to discuss the paleontologic details of other intermediate horizons we will pass to the consideration of the general affinities of the fossils from the important coals. To concentrate the data as much as possible the species obtained at various localities from the Quinnimont-Fire Creek coal* are tabulated in one list. The

* While the equivalence of the Quinnimont and Fire Creek coals is, as I have said above, not conclusively proven, they are certainly so near together, if not the same, that in a broad consideration, dealing with groups, they may be treated as at one stage.

*Plants of Quinnimont-Fire Creek Coal (see F, figures 1 and 2).*

| Species. | Stage or group. | Localities.* |
|---|---|---|
| *Adiantites* cf. *tenuifolius*, (Goepp.) Schimp. | Horsepen | P, RR, D, N, FR, H. |
| *Eremopteris* cf. *elegans*, (Ett.) Schimp. | Chester (Illinois) form. | RR, FR, H. |
| " *microphylla*, Lx. (?) | | N. |
| *Sphenopteris hoeninghausii*, Brongn. | | Q, P, RR, Bw, H. |
| " *dicksonioides*, (Goepp.) Schütze, form. | Alabama. Horsepen. | FC. |
| " *microcarpa*, Lx. | Horsepen. | Q (?), FR, RR, By (?). |
| " *divaricata* of Lesquereux | Tennessee | P, SC. |
| " *patentissima*, (Ett.) Schimp., nec Goepp. | Horsepen. | P, RA, FR. |
| " cf. *goepperti*, (Ett.) Schimp. non Dunk., nec (Münst.) Gein. | | SC, N. |
| *Pseudopecopteris muricata*, (Brongn.) Lx., form | Horsepen—Smiths Store. | Bw, RA, P, RR, D, N. |
| " " " " | Pilot. Dade. | D, RR, RA. |
| " cf. *dimorpha*, Lx. | Horsepen | FR, P, N. |
| " *latifolia*, (Brongn.) Lx., form. | Alabama. | D, RR, H. |
| *Megalopteris sewellensis*, Font. (?) | | FR, N. |
| " cf. *dawsoni*, Hartt | | Q. |
| *Neuropteris smithsii*, Lx., original. | Horsepen. Alabama | N, D, P, SC, RR. |
| " " " form. | War creek. | H, SC, N, P. |
| *Alethopteris*, sp. | | Q, SC, N, P. |
| *Bornia radiata*, (Brongn.) Schimp. | | P, RR. |
| *Calamites*, sp. | | A, D, Q. |
| *Asterophyllites minutus*, Andr. (?) | Horsepen | RR, D, H. |
| *Equisetites* cf. *occidentalis*, Lx. | Dade. Arkansas | D, H. |
| *Calamostachys lanceolata*, Lx., form. | Alabama. | RR. |
| *Annularia* cf. *ramosa*, Weiss. | Horsepen | D, H, RR. |
| " n. sp. | Horsepen—lower. | RR. |
| *Sphenophyllum*, n. sp | Horsepen. Alabama. | D. |
| *Lycopodites*, n. sp., Lx. | Horsepen. Alabama. | P, SC, D, RR. |
| *Lepidodendron sternbergii*, Brongn., form. | Horsepen. Alabama. | D, A, P. |
| " cf. *acuminatum*, (Goepp.) Newb. nec Rost. | | RR. |
| " *veltheimianum*, Stb. | | Q, RR, H, RA, SC. |
| *Lepidostrobus variabilis*, L. and H. (?), form | | SC. |
| *Lepidophyllum*, n. sp. | Horsepen. Alabama | D, RR. |
| " *campbellianum*, Lx. | Arkansas. | D, RR. |
| *Ulodendron*, sp. | | D, Q, Bw. |
| *Halonia*, sp. | | RR. |
| *Sigillaria*, sp. | Tennessee | By. |
| " cf. *dentata*, Newb | Ohio (?) | By, Bw. |
| *Trigonocarpus clavatus*, Stb. | Horsepen. Alabama. | Q, D. |
| *Rhabdocarpus*, n. sp. | Horsepen. Pocahontas. | FR, RR, D. |
| *Carpolithes*, n. sp., Lx. | Horsepen. Alabama. | SC. |

* A = Alaska; Bw = Beechwood; By = Beurys; D = Dimmock; FC = Fire Creek; FR = Fayette; H = Harveys (R. R.); N = Nuttall; P = Princes station; Q = Quinnimont; RA = Red Ash; RR = Rush Run.

second column refers to stages or groups in the Pottsville sections in Pennsylvania, Ohio, Tennessee, Virginia, Arkansas and Alabama. Thus "Ohio" indicates the Sharon coal in Ohio; "Ark." is used for the "coal-bearing shale" of Washington county, Arkansas, the flora of which is found to be largely identical with and clearly belonging to the Sewanee group of Tennessee, indicated by "Tenn." "Horsepen" is used for present convenience, without any intention to add to geologic nomenclature, to indicate a group of coals above the Pocahontas coal in the lower half of the Pottsville sections of Tug river and Great Flat Top mountain. They are more or less exposed near the school-house at Horsepen, near the fault-line at Smiths Store, near the mouth of War creek on Dry fork, and in Clarks gap on Great Flat Top.

A brief inspection of the second column in the accompanying tabulation shows that nearly one-half of the varieties or forms collected from this stage are characteristic or predominant in the lower middle portion of Tug River section, while a third of the entire number are either of too great a vertical range to possess any precise correlative value or they have not been noted by me from any of the other sections yet examined. Considering, then, only those species, forms or phases of species which have thus far been observed to be limited in their ascent and to be characteristic of certain horizons or groups, it becomes at once obvious that the great preponderance of the forms of this particular stage is also found in and mostly characteristic of the group represented at Horsepen and near Peeryville, in the Tug River basin, at Smiths Store, and at Clarks gap, on Great Flat Top mountain.* Several of the forms are more characteristic of higher stages, such as the Sewanee group in Tennessee and Arkansas and the Sharon coal of Ohio, while a few come from horizons whose comparative paleontologic stage is not yet known to me.

### *FLORA OF THE SEWELL COAL AND ITS RANGE.*

Treating in the same way the plants obtained from the Sewell coal at various localities, it appears that nearly three-fourths of the forms are characteristic of the Sewanee group in Tennessee, which includes the "coal-bearing shale" of Washington county, Arkansas, and to which probably belongs the flora of the Sharon coal in Ohio. At all the localities along the river the plants † gathered from the Sewell coal are at once

* It requires no extensive study of the floras of the coals at Horsepen and Smiths Store—both localities concerning which there has been much doubt and difference of opinion on account of their being more or less isolated and against the fault-line—to show their intimate relation and identity with those between Jacobs creek and Peeryville, on Dry fork, or in Clarks gap.

† It should be borne in mind that, as remarked at the beginning of this paper, I treat as forms, often less than varietal in rank, those variations of species which appear, so far as the study of the Pottsville floras has extended, to have been much restricted in time, and seem therefore tolerably characteristic, at least locally, of fairly definite stages or groups.

*Plants from Sewell Coal (see I, figure 2).*

| Species. | Group or stage. | Localities.* |
|---|---|---|
| *Eremopteris* cf. *elegans*, (Ett.) Schimp., form | Ohio | H. |
| " *cheathami*, Lx. | Tennessee and Arkansas | N, C. |
| *Sphenopteris hoeninghausii*, Brongn. | | Th. |
| " cf. *larischii*, (Stur) Lx. | Georgia and Alabama | H. |
| " *microcarpa*, Lx. | Horsepen. Alabama | H. |
| " *flexicaulis*, Lx. | Tennessee and Arkansas | H. |
| " cf. *royi*, Lx. | Tennessee | N. |
| " *communis*, Lx. | Tennessee | N. |
| *Pseudopecopteris muricata*, (Brongn.) Lx., form | Tennessee | Th, H, C. |
| " " " " | Arkansas | C. |
| " *macilenta* of Lesquereux, form | Arkansas | Th, N. |
| " *dimorpha*, Lx. | Tennessee | Th, TK. |
| *Neuropteris elrodi*, Lx., form | Tennessee | Mc, Th, C. |
| " n. sp., Lx. | Tennessee | Mc. |
| " *biformis*, Lx., form | Tennessee | Mc, C. |
| " *smithsii*, Lx., form | War creek | Mc, TK, SC, H, N. |
| " n. sp. | Doran | Th. |
| *Odontopteris newberryi*, Lx. (?) | Ohio | Mc. |
| *Callipteridium*, n. sp., Lx. | Tennessee | C, N. |
| " n. sp. | Arkansas | C. |
| *Alethopteris* cf. *lonchitica*, (Schl.) Goepp. | | Th, Mc, N. |
| " *evansii*, Lx. | Tennessee | C, N. |
| *Pecopteris* (?) *serrulata*, Hartt, non Heer, nec (Lx.) Schimp. | Tennessee | Th. |
| *Calamites*, sp. | | Th, N. |
| *Asterophyllites erectifolius*, Andr. | Tennessee, Arkansas and Ohio ("Waverly") | Mc, TK, H, Th. |
| " *gracilis*, Lx., nec (Stb.) Brongn. | Arkansas and Georgia | Mc. |
| *Annularia* cf. *ramosa*, Weiss | Horsepen | Mc, Th. |
| " *radiata*, (Brongn.) Stb. | Arkansas | Th. |
| *Calamostachys lanceolata*, Lx. | Arkansas and Tennessee | Th, H. |
| *Macrostachya*, n. sp. | Arkansas. | C. |
| *Sphenophyllum*, n. sp. | Horsepen. Alabama | H. |
| *Lepidodendron veltheimianum*, Stb., form | Tennessee | C. N. |
| " *sternbergii*, Brongn. | Horsepen. Alabama | SC. |
| *Lepidophyllum*, n. sp. | Horsepen. Alabama and Georgia | Th. |
| " *campbellianum*, Lx. | Arkansas, Tennessee and Pennsylvania | SC. |
| *Sigillaria* cf. *reticulata*, Lx., nec (Stb.) Mill. | Arkansas (?) | C. |
| " *dentata*, Newb. (?) | Ohio | Mc. |
| *Whittleseya elegans*, Newb. | Tennessee and Ohio | Mc. |
| *Rhabdocarpus*, n. sp. | | TK, Mc, H, SC, Th. |
| " n. sp., Lx. | Cordova (Alabama) | Mc, SC. |
| *Trigonocarpus oliviæformis*, L. and H. (?) | Arkansas | TK, Mc (?), H, Th. |
| *Cardiocarpus elongatus*, Newb. | Ohio | Mc, TK. |
| " *minor*, Newb. (?) | Ohio | TK. |
| " cf. *bicuspidatus*, (Stb.) Newb. | Tennessee, Arkansas and Ohio | SC. |

*C = Cunard; H = Harveys; Mc = Macdonald; N = Nuttall; SC = Stone Cliff; Th = Thurmond; TK = Turkey Knob.

seen to be closely related to the flora of the main Sewanee coal of Tennessee and of the "coal-bearing shale" of Washington county, Arkansas. The material from the Cunard mine, opposite Sewell, is astonishingly similar in most respects to that found at Rockwood or Tracy City, in the former state.

While the paleontologic evidence makes it reasonably certain that the Sewell coal was formed at a time relatively near that of the main Sewanee coal, the inference that they may be the same coal is far from demonstration. Only those who have a strong predisposition to discover the continuity of individual sandstones or coals throughout the Appalachian basin will, possibly, anticipate from this evidence, perhaps largely circumstantial in character, that the two valuable coking coals are the same, the "Emory sandstone" above and the "Sewanee conglomerate" below the coal in Tennessee being equivalent to the Homewood and upper Piney Creek conglomerate respectively in the New River section.

### *FOSSIL PLANTS OF THE "HOMEWOOD SANDSTONE."*

One other of the plant beds in the New River section deserves mention, since its paleontologic affinities will serve as an additional illustration in the evidence touching upon the relation of the "Pottsville" of Ohio to that of the central Appalachian region.

From a parting in the Homewood sandstone (see *L*, figure 2) in the vicinity of Anstid fragments of the following flora were gathered:

*Plants from Homewood Sandstone (see L, figure 2).*

| Species. | Stage or group. |
|---|---|
| *Archæopteris*, n. sp., related closely to | Ohio and Pennsylvania. |
| *Eremopteris*, sp. | Ohio. |
| *Sphenopteris furcata*, Brongn. | Ohio, Pennsylvania and Coal Measures. |
| *Sphenopteris* cf. *divaricata* of Lesquereux, form. | Tennessee. |
| *Pseudopecopteris* cf. *acuta* of Lesquereux | Coal Measures. |
| *Neuropteris*, sp. | Ohio and Coal Measures. |
| *Odontopteris gracillima*, Newb. | Ohio. |
| *Alethopteris* cf. *ambigua*, Lx. | Coal Measures. |
| *Cardiocarpus bicuspidatus*, (Stb.) Newb. | Ohio, Arkansas and Pennsylvania. |
| *Triletes*, sp. | |

A glance at the above list shows that we have here to do with a flora the preponderant elements of which are characteristic of the Sharon coal of Ohio. One of the species, a form identified by Professor Lesquereux as *Sphenopteris divaricata*, is characteristic of the Sewanee stage of Ten-

nessee, though I have rarely seen it from a higher horizon. Several of the species belong properly to the Lower Productive Coal Measures.

### *PALEONTOLOGIC RELATION OF NEW RIVER SECTION TO SHARON COAL IN OHIO.*

This flora is not presented as proof that it represents the horizon of or is synchronous with the Sharon coal in Ohio. It illustrates a fact observed in every section of the Pottsville yet examined, namely, that in the thick sections of this series the plants of the Sharon coal are found only in the upper part of the section, and that, though straggling forms begin to appear near the middle of the series, we do not find the association of species characteristic of the Sharon coal to prevail and stand forth predominantly until we near the top of the series. In every case the paleontology of these greatly thickened sections of the Pottsville shows the stage of the Sharon coal to be in the upper half of the series and relatively high therein. Although its fossils relate it closely to the Sewanee of Tennessee and the coal-bearing shale of Washington county, Arkansas, even allowing for a higher range of the species in passing southward, it can hardly be older than the main Sewanee, while there is some evidence that it is more recent. I can find no satisfactory paleontologic support for the view * that "this Sharon bed and its thin rider appear to represent all the coals in the New River group."

## Equivalence of Pottsville Sections.

The foregoing paleontologic evidence has a direct bearing on the important question of the equivalency of the various sections of the Pottsville in the different portions of the Appalachian basin. The opinion seems generally to prevail that the time covered by the Pottsville series in the various portions of the Appalachian trough is the same, or very nearly the same, and that the very thick sections simply represent expansions of some or all of the members present in the thin sections. Thus Professor I. C. White, in his invaluable bulletin on the stratigraphy of the bituminous coal field,† argues that the Virginia-Kentucky section, 2,000 feet or more in thickness, represents an expansion of a series never over 300 and sometimes less than 200 feet thick in Ohio. If this be true, then the lower 1,500 feet, in round numbers, of the southern section must cover the time represented by the "Sharon conglomerate," a formation only from 20 to 40 feet thick, or even wanting in places, in Pennsylvania and Ohio. On the contrary, the evidence of the

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*See I. C. White: Bull. U. S. Geol. Survey, no. 65, p. 202.

†Op. cit., pl. ii, fig. 2.

fossils, so far as yet observed, goes to show that, although members of the thin sections are usually much expanded in the thick sections, still the greater part of the increase is due to earlier sediments underlying the equivalents of the thinner sections and lithologically belonging to the same series.

In general, it may be said that, so far as the fossils have been gathered and studied (including those from the type section of the Pottsville in the southern anthracite basin), those from the thin sections are found in the upper portion of the thick sections, those of the moderately thick sections being present in about the same interval, measuring downward, in the much thicker sections, while those from the basal portions of these thicker sections are more or less unique and still farther removed from the flora of the Lower Coal Measures.

The floras of the middle of the very thick sections of the Pottsville appear to be largely identical with and to present the general facies of the Ostrau-Waldenburg floras of Moravian Silesia, while those from the base of the sections have much in common with the Culm or Carboniferous limestone series of the old world.

### Problem of Correlation of Base of Pottsville Series.

The facts that (1) along the northern rim of the Appalachian coal field and in the Mississippi Valley states the rocks (Pottsville) between the true Coal Measures above and the Lower Carboniferous series with marine fossils below appear to carry only the fossils of the upper portion of the moderately thick and very thick Pottsville sections, seeming really to be equivalent, practically, to only the corresponding portions, measuring downward, of the thick sections, and (2) the increasingly unique and ancient character of the lower flora in the very thick sections, stand in evidence to show either that there is a time-break between the base of the thin section and the top of the Lower Carboniferous, which break should represent at least the time required for the deposition of the greater portion of the thick section, or that the thick section of the Pottsville overlaps in time the Lower Carboniferous in the northern and Mississippi Valley states, the floras of the lower portions of the thick section being in the latter case contemporaneous with marine invertebrates in the Lower Carboniferous of the central states. This problem, as well as the consequent question of the propriety of including the entire Pottsville series or "Conglomerate series" of the southern Appalachian region in the Upper Carboniferous, may be considered to better advantage when the examination of the material from the very thick section of eastern Kentucky and from the southern anthracite field of Pennsylvania is completed.

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# DISINTEGRATION OF THE GRANITIC ROCKS OF THE DISTRICT OF COLUMBIA

BY GEORGE P. MERRILL

(*Read before the Society December 29, 1894*)

CONTENTS



## INTRODUCTION.

The belt of ancient crystalline rocks bordering along the east side of the Appalachian system south of the glacial limit affords abundant opportunity for the study of rock disintegration and decay as manifested through the somewhat complex processes commonly grouped under the term "weathering." The small area comprised within the northwestern portion of the District of Columbia is particularly favorable to the observation and study of the chemical and physical processes involved. This is due, first, to the fact that in numerous instances one is enabled to study all phases of the transition from sound, fresh rock to arable soil in a single outcrop, where all danger of admixture of foreign material is reduced to a minimum, and, second, to the equally interesting if not important fact that the time-limit of such disintegration can be drawn with a considerable degree of accuracy. The investigations here detailed were undertaken with a view to ascertain, so far as possible, both the

physical and chemical changes which have taken place in this transformation and incidentally to discover the causes thereof.

## Description of Locality.

In the accompanying illustration is shown a very typical exposure as it may be seen today by the roadside on Broad branch, an affluent of Rock creek, nearly a mile north of Pierce's mill. The height of the bluff as here shown is not more than 18 feet. The roots shown in the upper part are from plants and shrubs, as well as from trees—both pines and various forms of hardwood growth, such as cover the hill—and which have here been exposed through the removal of a part of the rock in the work of building the roadway. As is seen in the plate, the rock is divided by three principal sets of joints, one of which, running in a direction nearly north and south and dipping toward the west, gives the flat surfaces facing the observer. A second series cuts across these joints nearly at right angles—that is, east and west—while a third series, running northwest and southeast, cuts both the other series obliquely and dips into the hill at an angle of about 35 degrees from the vertical. Several minor series cut these at various angles, but are not sufficiently evident in the view to need mention.

These joints have afforded passageways for the meteoric waters which have been largely instrumental in bringing about the disintegration. The rock in its fresh condition is a strongly foliated micaceous granite,* showing to the unaided eye a finely granular aggregate of quartz and feldspars arranged in imperfect lenticular masses from 2 to 5 millimeters in diameter, about and through which are distributed abundant folia of black mica. In the thin-section the structure is seen to be cataclastic. Quartz and black mica are the most prominent constituents, though there are abundant feldspars of both potash and soda-lime varieties, which, owing to their limpidity, can by the unaided eye scarcely be distinguished from the quartz. The potash-feldspar has in part a microcline structure. Aside from these minerals a primary epidote, in small granules and at times quite perfectly outlined crystals, is a strikingly abundant constituent. Small apatites, a few flakes of a white mica (sericite), and widely scattering black tourmalines and iron ores complete the list of recognizable minerals.

The outcrops from which the samples for the analyses to which I wish to first call attention were selected are shown in the plate. At the very bottom the rock is hard, fresh and compact, without trace of decomposi-

*It is presumably scarcely necessary to state that the writer's views of 13 years ago regarding the possible sedimentary nature of many of the District rocks have undergone a radical change.

DISINTEGRATING GRANITIC ROCKS IN THE DISTRICT OF COLUMBIA.

tion products other than as indicated by minute infiltrations of calcite from above. Just above the level of the small creek which flows at the foot of the bluff, at the point indicated by the first series of right-and-left joints near the center of the view, the character of the rock changes quite suddenly, becoming brown and friable, though still retaining its form and easily recognizable granitic appearance. A few feet above, a third zone begins, in which the rock is converted into sand and gravel and which becomes more and more soil-like to the top of the bank, where it becomes admixed with organic matter from the growing plants. The amount of organic matter is always quite small, however, and in making the analyses care was taken to remove such as was recognizable in the form of rootlets, leaves and twigs.

## Analyses and their Discussion.

### *BULK ANALYSES.*

Bulk analyses of each of the three types—(I) fresh gray rock, (II) decomposed brown, but still moderately firm and intact rock, and (III) soil—yielded Professor R. L. Packard the results given below:

| | I. | II. | III. |
|---|---|---|---|
| Ignition | 1.22 | 3.27 | 4.70 |
| $SiO_2$ | 69.33 | 66.82 | 65.69 |
| $TiO_2$ | not det. | not det. | 0.31 |
| $Al_2O_3$ | 14.33 | 15.62 | 15.23 |
| $FeO$ | 3.60 | 1.69 | 4.39 |
| $Fe_2O_3$ | .... | 1.88 | |
| $CaO$ | 3.21 | 3.13 | 2.63 |
| $MgO$ | 2.44 | 2.76 | 2.64 |
| $Na_2O$ | 2.70 | 2.58 | 2.12 |
| $K_2O$ | 2.67 | 2.04 | 2.00 |
| $P_2O_5$ | 0.10 | not det. | 0.055 |
| | 99.60 | 99.79 | 99.765 |

It is at once evident from the above that the transition from fresh rock to soil has been brought about with very little change in ultimate chemical composition—an assumption of some 3.5 per cent of water, a change of the ferrous oxide to ferric forms, doubtless more or less hydrated, and a slight decrease in the total amounts of silica, lime, potash and soda being the more conspicuous features. How slight this change has been is best brought out in the accompanying table, in which each analysis is recalculated to a water-free basis. It should be noted, however, that the term water-free, as here used, is not absolutely correct, since the loss on ignition is undoubtedly in part due to carbonic acid from secondary calcite and organic matter.

| | I. | II. | III. |
|---|---|---|---|
| $SiO_2$ | 70.47 | 69.23 | 69.10 |
| $Al_2O_3$ | 14.56 | 16.18 | 16.07 |
| $TiO_2$ | .... | .... | 0.31 |
| $FeO$ | 3.66 | 1.75 | 4.61 |
| $Fe_2O_3$ | .... | 1.95 | |
| $CaO$ | 3.27 | 3.24 | 2.76 |
| $MgO$ | 2.49 | 2.86 | 2.77 |
| $Na_2O$ | 2.74 | 2.68 | 2.23 |
| $K_2O$ | 2.71 | 2.11 | 2.10 |
| $P_2O_5$ | 0.10 | .... | 0.06 |
| | 100.00 | 100.00 | 100.01 |

An apparent loss of 1.37 per cent of $SiO_2$; 0.040 per cent of $CaO$; 0.51 per cent of $Na_2O$; 0.61 per cent of $K_2O$, and 0.04 per cent of $P_2O_5$, or not quite 3 per cent of the total constituents, and a corresponding proportional increase of the less soluble alumina, iron and magnesia, is all the change indicated by a purely chemical, bulk analysis. It is evident that here the chief alteration in the conversion of the barren rock into arable soil is physical, attended probably with a partial change in the mode of combination of the various elements.

### *ANALYSES OF MATERIAL SEPARATED BY SOLVENTS.*

In order to ascertain what this possible change in combination might be, samples of the soil were treated for a period of ten days with (1) cold distilled water; (2) cold distilled water through which carbonic acid gas was kept bubbling; (3) acetic acid, and (4) hydrochloric acid of one-fourth normal strength—that is, one part of acid of the specific gravity of 1.20 to three parts of water. Five hundred grams were used in each of the first three cases and 50 grams in the fourth. The results obtained were as follows:

The pure water extract (1) amounted to but 0.069 grams (0.0138 per cent), which yielded, qualitatively, reactions for potash and soda and a bare trace of lime, but no iron, alumina or silica. The carbonic acid extract (2) yielded 0.0985 grams (0.0197 per cent), which gave reactions for lime, potash, soda, alumina and iron, but no appreciable amount of silica.

The acetic acid extract (3) yielded Professor Packard the quantitative results below:

| | | | |
|---|---|---|---|
| $K_2O$ | .024 grams | = | .0048 per cent. |
| $Na_2O$ | .007 " | = | .0014 " |
| $Fe_2O_3$ | .106 " | = | .0212 " |
| $Al_2O_3$ | .129 " | = | .0258 " |
| $MnO$ | .047 " | = | .0094 " |
| $CaO$ | .079 " | = | .0158 " |
| $MgO$ | .019 " | = | .0038 " |
| | .411 " | = | .0822 " |

The hydrochloric acid extract (4) yielded:

| | | | | |
|---|---|---|---|---|
| $SiO_2$*........................ | .0545 | grams | = 0.109 | per cent. |
| $Al_2O_3$........................ | .6620 | " | = 1.324 | " |
| $Fe_2O_3$........................ | .9061 | " | = 1.812 | " |
| $CaO$........................ | .024 | " | = 0.048 | " |
| $K_2O$........................ | .0887 | " | = 0.177 | " |
| $Na_2O$........................ | .0698 | " | = 0.139 | " |
| | 1.8051 | " | = 3.609 | " |

*ANALYSES OF MATERIAL MECHANICALLY SEPARATED.*

In order to make more clear the change in physical conditions which the rock had undergone, 400 grams of the pulverulent material, free from roots and other recognizable organic debris, were submitted to mechanical separation by passing through sieves of varying degrees of fineness. The 17 grams tabulated below as "silt" were obtained by washing the 43 grams of material which passed through fine bolting cloth of 120 meshes to the lineal inch, and represents the impalpable mud which remained for some time in suspension, while the 26 grams of "fine sand" sank in the course of a few moments to the bottom of the beaker.

The results of this mechanical separation are as follows:

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Silt........................ | 17 | grams: | largest | grains | 0.1 | millimeters | in | diameter. |
| Fine sand................ | 26 | " | " | " | 0.18 | " | " | " |
| Sand..................... | 45 | " | " | " | 0.25 | " | " | " |
| Sand..................... | 15 | " | " | " | 0.65 | " | " | " |
| Sand..................... | 44 | " | " | " | 1.00 | " | " | " |
| Sand..................... | 94 | " | " | " | 1.5 | " | " | " |
| Coarse sand.............. | 118 | " | " | " | 2.00 | " | " | " |
| Gravel.................... | 41 | " | " | " | 8.00 | " | " | " |
| Total.............. | 400 | | | | | | | |

The coarser of these particles, like the gravel and the coarse sand, are of a compound nature, being aggregates of quartz and feldspar, with small amounts of mica and other minerals. In the finer material, on the other hand, each particle represents but a single mineral, the process of disaggregation having quite freed it from its associates, excepting, of course, in the case of microscopic inclusions, which could be liberated only by a complete disintegration of the host itself. These particles as seen under the microscope are all sharply angular and in many cases surprisingly fresh and undecomposed. The mica shows the greatest amount of alteration, the change consisting mainly in an oxidation of its ferruginous constituent, whereby the folia become stained and re-

*This silica is that taken up in acid solution only. A much larger amount would have been obtained by treatment of the residue with carbonate of soda solution (see p. 326).

duced to yellowish brown shreds. The feldspars are in some cases opaque through kaolinization, but in others are still fresh and unchanged even in the smallest particles. The finest silt, when treated with a diluted acid to remove the iron stains, shows the remaining granules of quartz, feldspar and epidote beautifully fresh and with sharp, angular borders, the mica being, however, almost completely decolorized and resembling sericite more than biotite. An analysis of this silt yielded the results given further on.*

Column I shows the actual results obtained, and column II the same recalculated to a water-free basis. In columns III and IV are given the attempts to determine the soluble and insoluble portions of the same silt. The soluble portion was that obtained by digestion, without further pulverization, for two hours in hydrochloric acid of one-fourth normal strength, the insoluble residue being treated for a like period with carbonate of soda solution in order to extract the gelatinous silica set free by the acid. This insoluble residue was in the form of a beautiful fine, white sand made up of very sharply angular particles of quartz, fewer feldspars, an occasional epidote and a considerable sprinkling of almost amorphous material, in part kaolin and in part a gum-like substance, evidently representing a transitional stage of the feldspathic alteration into kaolin. The analysis of the soluble portion is unfortunately incomplete, owing to the cracking of a beaker and consequent loss of a portion of the material. The insoluble residue from the two grams treated amounted to 1.206 grams, or 60.3 per cent, and the soluble portion by difference to 0.7949 grams, or 39.7 per cent.

*Analysis of Silt.*

| | I. Actual analysis. | II. Recalculated. Water-free. | III. Soluble portion (39.7 %). | IV. Insoluble portion (60.3 %). |
|---|---|---|---|---|
| Ignition | 8.12 | 0.00 | ........ | 1.61 |
| $SiO_2$ | 49.39 | 53.74 | Extracted in HCl .... 2.83; Extracted in $Na_2CO_3$ .. 28.08 | 61.85 |
| $Al_2O_3$ | 23.84 | 25.94 | 23.21 | 22.21 |
| $Fe_2O_3$ | 3.69 | 4.01 | 11.26 | 1.36 |
| CaO | 4.41 | 4.79 | Undetermined | 4.80 |
| MgO | 4.60 | 5.00 | Undetermined | traces |
| $Na_2O$ | 3.36 | 3.65 | Undetermined | 4.56 |
| $K_2O$ | 2.49 | 2.71 | Undetermined | 1.77 |
| | 99.90 | 99.84 | | 98.16 |

* Unless otherwise stated, all analyses here given were made by the writer of this paper.

From these analyses it would appear that of the 17 grams of silt, representing 4 per cent of the total disintegrated material, only 39.7 per cent is soluble; and, further, that a very considerable proportion of the insoluble residue, as indicated by the high percentages of alkalies and lime, still consists of unaltered soda lime and potash feldspars, the iron and magnesia alone having been largely removed.

### *CONDITIONS AFFECTING THE RESULTS.*

These results are not quite what one would be led to expect from a perusal of the literature bearing upon the subject of rock decomposition. As long since noted by J. G. Forchhammer, G. Bischof, T. Sterry Hunt and others, the ordinary processes of decay in siliceous rocks containing ferruginous protoxides and alkalies consists in the higher oxidation and separation of the protoxides in the form of hydrous sesquioxides and a general hydration of the alkaline silicates, accompanied by the formation of alkaline carbonates, which being readily soluble are taken away nearly as fast as formed. More or less silica is also removed, according to the amount of carbonic acid present—a portion of the alkalies forming soluble alkaline silicates when the supply of the acid is insufficient to take them all up in the form of carbonates. The apparent anomaly here shown is partially explained by examination of the various separations with the microscope. Thus the low percentage of silica is found to be in large part due to the fact that the residual quartz granules are in many cases too large to pass the 120-mesh sieve, or, if passing, have been largely separated in the process of washing. Further, it is found that the sifting has served to concentrate the small epidotes in the fine sand, and a portion of them have even come over with the silt. The presence of this epidote also explains in part the high percentage of lime shown, since the mineral itself carries some 20 to 24 per cent. of this material. The large percentages of magnesia, soda and potash cannot, however, be thus accounted for, and we are led to infer that either these elements are there combined in minute amorphous zeolitic compounds, unrecognizable as such under the microscope, or, as seems to me more probable, the feldspathic constituents to which the alkalies are to be originally referred have undergone a mechanical splitting up rather than a chemical decomposition. This view is to a certain extent borne out by microscopic studies, but it is difficult to measure by the eye the relative abundance of these constituents with sufficient accuracy to enable one to form any satisfactory conclusion. The magnesia must come from the shreds of mica, many of which, from their small size and almost flocculent nature when decomposed, would naturally be found in the silt obtained as stated.

It is to be noted that the magnesia, together with the iron, exists almost wholly in a soluble form.

### *ANALYSES OF MATERIAL FROM OTHER LOCALITIES.*

Not wishing to attach too much importance to analyses of samples from a single locality, others were obtained from along the same belt. In I of the columns below, is shown the composition of a soil from the road-cut west of Pierce's mill, and in II and III material from the deeper cut where this road crosses Connecticut avenue extended, number II being from some 3 feet beneath the surface where it was overlaid by a thin layer of the Potomac gravel, and III from the bottom of the cut some 20 feet below the present surface. The last sample, though sufficiently soft to be readily removed with the fingers, showed scarcely any of the oxidation which discolors the superficial portions, thus indicating that oxidation itself is not an essential part of the disintegrating process, but merely incidental to it. In column IV is given an average of the three analyses, and in V the same calculated on a water-free basis. For purposes of comparison the results given in column III, page 323, are here repeated in column VI.

| | I. | II. | III. | IV. | V. | VI. |
|---|---|---|---|---|---|---|
| Ignition | 5.51 | 3.87 | 3.97 | 4.45 | ..... | ..... |
| $SiO_2$ | 64.25 | 64.87 | 63.42 | 64.15 | 67.13 | 69.10 |
| $Al_2O_3$, $Fe_2O_3$ | 19.97 | 21.32 | 23.08 | 21.26 | 23.29 | 20.99 |
| $MgO$ | 3.12 | 3.01 | 2.69 | 2.94 | 2.07 | 2.77 |
| $CaO$ | 3.18 | 2.90 | 3.01 | 3.03 | 3.17 | 2.76 |
| $K_2O$ | 2.17 | 2.39 | 2.15 | 2.24 | 2.34 | 2.10 |
| $Na_2O$ | 1.55 | 1.86 | 1.77 | 1.72 | 1.80 | 2.23 |
| | 99.75 | 100.22 | 100.09 | 99.79 | 99.80 | 99.95 |

It should be stated that in all these cases special care was exercised in securing samples from areas which had never been under cultivation in order that there might be no possible contamination or acceleration of decay through the action of fertilizers or of plowing. Equal care was taken to obtain material in place and where it had undergone only the leaching of surface waters percolating downward from above. The results, though showing a somewhat more advanced condition of decay, agree even more closely than could be expected from samples collected from widely separated localities.

### TIME-LIMIT OF DISINTEGRATION.

A possible time-limit to the beginning of this disintegration is furnished by the Potomac (Cretaceous) and more recent deposits of the region.

While in the first case described the disintegrated granitic material forms the present surface soil, there are abundant street and road cuttings in the northwestern part of the District where the unconsolidated sands and gravels of the Potomac and Lafayette formations as described by Messrs McGee * and Darton are to be found overlying it at this same or greater altitudes and in beds of no inconsiderable thickness. In all such cases the line of demarkation between the two is well defined and there is no apparent admixture of materials.

Although both the Potomac and Lafayette gravels contain materials undoubtedly derived from these older crystalline rocks, yet we do not find along the line of contact anything to indicate that they were laid down on surfaces such as now exist or were other than fresh and hard. There are included in the lower part of the gravel none of the large angular masses of quartz from the veins, such as now so commonly dot the surface, nor natural joint-blocks of the granite. On the supposition that the beginning of the present decomposition antedates the laying down of these gravels, we must assume a submergence and deposition in waters so quiet as not to disturb the rotted materials. That such a condition is impossible becomes apparent when we consider the character of the deposits themselves. As described, they consist of quartzite pebbles derived evidently from the axial quartzites of the Blue ridge, quartz pebbles identical with the vein-quartz of the region and from which they were evidently derived, and a loosely consolidated arkose made up of angular grains of quartz and of feldspar or flakes of kaolin, scales of mica, etcetera. To this list I would add for the region about Washington an abundant sprinkling of well rounded pebbles of a felsitic quartz-porphyry, which, like the quartzite, was evidently derived from the Blue ridge. The character of the accumulations, as Mr McGee states,† are—

"Just such as would be formed by the assortment and deposition of the different materials by '*powerful currents*' (author's italics), but the quantity of coarse material is greater than would result from simple admixture of the disintegrated gneiss of the Piedmont zone and such proportion of the Blue Ridge quartzite, vein-quartz, etcetera, as appear to be mingled with it, suggesting that the portions of the formation now exposed were littoral, and that the finer materials were swept into deeper, offshore waters."

The pebbles of this formation, it should be stated, are almost invariably well rounded by water-action and occur of all weights up to 200 and more pounds. It seems safe to assume that these somewhat sporadic, larger forms are due to drifting ice and for our present purposes may be left out of consideration.

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* Am. Jour. Sci., February, March, April and May, 1888.

† Op. cit., February, 1888, p. 139.

Aside from these, an abundant sprinkling of well rounded pebbles of from one to 5 or 6 pounds weight each form one of the most characteristic features of the gravels. It seems impossible that such material could have been brought to its present position except by the aid of currents or wave-action so energetic as to erode the then existing decomposed granitic material which the lithologic character of the Potomac formation, as above given, tends to prove existed.

The point which I now wish to make is, however, that all such material was removed from its position *in situ* prior to the deposition of these gravels. The fact that everywhere along the lower part of the deposits there is a notable lack of the angular quartz fragments and jointed blocks of granite such as now form so conspicuous a feature leads, as it seems to me, irresistibly to the conclusion that prior to their deposition all loose and partially decomposed matter was eroded away and the later deposition made upon hard and comparatively fresh surfaces. Hence the disintegration as we now find it, extending in some cases to a depth of 50 or more feet, is almost wholly post-Cretaceous.

That this apparently rapid rate of decomposition is not anomalous is well illustrated in a large dike of diabase at Medford, Massachusetts, the petrographic nature of which has been made known by Dr Hobbs.* Portions of this dike are in an advanced stage of disintegration, which is undoubtedly postglacial. The writer hopes todescribe the changes which have here taken place in another paper.

As a matter of passing interest and as bearing upon the same general subject, I may mention the fact that the pebbles of felsitic rock noted as occurring in the Potomac gravels are, as a rule, in a condition of such complete decomposition (kaolinization) as to fall to pieces except when handled with the greatest care. Indeed, wherever exposed through the cutting of streets, they fall away quickly to loose sand. Nevertheless, the outlines of these pebbles are sharply oval and the surfaces smooth and almost polished. They are beyond question water-worn pebbles, and as such could only have assumed their rounded form when their materials were in an entirely fresh and undecomposed condition—that is to say, their decomposition was posterior to their deposition, or at least to the time of their becoming water-worn.

This particular occurrence I regard of interest as showing, first, the great depth to which disintegration can be carried without excessive decomposition, and, secondly, the relative rapidity of the process. I should add that in areas examined farther to the west and south, beyond the limit of the Cretaceous submergence, I find similar rocks in a state

* Bull. Museum of Comparative Zoölogy, vol. xvi, no. 1, 1888.

of much more advanced decomposition, being in most cases at the immediate surface reduced to the condition of residual clays.

## Causes of Disintegration.

It is evident from what has gone before that the changes which have taken place in the mass of rock are as much in the nature of disintegration as decomposition. The question, then, very promptly arises, what are the agencies which have been instrumental in bringing about a disintegration which in extreme cases extends to a depth of 50 feet and upward.

It is customary to divide the forces commonly active in promoting rock-weathering into two groups—physical and chemical. Of the physical agencies, temperature changes alone need be considered in this connection;* of the chemical agencies, oxidation, hydration and solution.

It has been abundantly demonstrated in the work of the various experiment stations that at a depth of a few inches beneath the surface the daily variation in temperature is very slight, and we may safely assume that at depths of a few feet both the annual and daily variations are also so small as to be practically inoperative. The purely physical agencies may be therefore omitted from further consideration.

Of the chemical agencies, it is evident that the process of solution has not been sufficiently active to carry away more than an extremely small proportion of the material, but has contented itself with bringing a fractional part of the elements into a new state of combination. These facts, would seem to render it very doubtful if bacterial agencies, as suggested by A. Müntz and others,† have operated to any appreciable extent.

Oxidation has manifested itself in the superficial portions in the partial destruction of the protoxide silicates, but even this action to a large extent ceases at a depth of 20 feet below the surface.

Of all the agencies enumerated, hydration seems most pronounced and most nearly universal. Now, hydration in a rock-mass, without loss of any constituent, necessitates expansion, and as the various minerals undergoing this process will expand unequally, a tendency toward disintegration is manifested, even when the process has stopped short of the complete kaolinization of the feldspars. This fact was impressed upon me in a very striking manner some years ago, and inasmuch as I do not

* In the discussion which followed the reading of this paper before the Geological Society of Washington in January, 1895, the question was raised as to the possible efficacy of capillarity in promoting disintegration. The writer can only say that he is unable to conceive of the direct physical action of capillarity as being other than neutral. As a secondary factor in promoting hydration, it is undoubtedly of importance.

† Comptes Rendus de l'Academie des Sciences, vol. cx, 1890, p. 1370.

find reference to like phenomena in existing literature I may be excused for describing it somewhat in detail.

While excavating in the tunnel for the water-works extension in Washington, sharply angular natural joint-blocks of granitic and dioritic rocks with smooth, even faces, were brought to the surface from varying depths up to a hundred and some odd feet. Much of the material was perfectly fresh and sound, and has been utilized for road-making and building purposes. Much, on the other hand, while apparently fresh and showing on casual inspection no signs of decomposition, gave forth only a dull sound when struck with a hammer and showed a lusterless fracture. Blocks of this last type nearly always rapidly disintegrated into coarse sand after short exposure, though manifesting no other sign of mineralogic change than a whitening of the feldspars. So marked was this feature that even the workmen noticed it, and on more than one occasion samples of this or the sound rock were brought me by builders who questioned its durability, inasmuch as some of the material "slacked like lime," as they expressed it, on exposure.

My explanation has always been that the various minerals composing the rock (with the exception of the quartz) underwent a partial hydration from percolating waters, but, held in the vise-like grip of the surrounding rocks, were unable to expand to the extent of loss of cohesion and consequent disintegration. As soon as freed from compression expansion and presumably further hydration took place, the mass became spongy, and, freely absorbing water, fell into sand and gravel.

This idea led me to make a few experiments toward ascertaining the actual amount of expansion the rock undergoes during this transformation. Barring the error due to loss of material by solution, it is evident that a fair approximation may be gained by a comparison of the weight, bulk for bulk, of the fresh and decomposed material. It being obvious that in order to fulfill existing conditions no great refinement of methods was essential, I contented myself with taking a quantity of the air-dried material and measuring it in straight, cylindrical glass vessels, bringing it to the approximate condition of the soil by tamping with water, and afterward drying and weighing. By comparing the weights per cubic centimeter thus obtained with the weight of a cubic centimeter of the fresh rock, as shown by its specific gravity, I was able from an average of several determinations to obtain an approximation of 1.88, which represents with a fair degree of accuracy the average amount of expansion which the rock has here undergone in passing from its fresh condition into that of undisturbed soil a foot beneath the surface.

Figure 1.—View of Butte; Core not exposed.

Figure 2.—Summit of largest Butte.

TEPEE BUTTES.

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# TEPEE BUTTES

BY G. K. GILBERT AND F. P. GULLIVER

*(Read before the Society December 27, 1894)*

CONTENTS



## INTRODUCTION.

In the Pierre shales of Colorado are limestone masses of peculiar character. Their height is greater than their width and all dimensions are of a size to be measured by feet or yards. Resisting erosion much better than the shales, they stand above the general surface. Their fallen fragments protect sloping pedestals of shale, and their positions are marked in the landscape by conical knolls or buttes. The formal resemblance of these buttes to the conical lodges, or tepees, of the Sioux and other Indians has led us to call them distinctively *tepee buttes.* It will be convenient also to call the masses of limestone *tepee cores* and their material *tepee rock.*

## DESCRIPTION OF THE CORES.

### *GEOLOGIC RELATIONS.*

The Pierre group, as developed in the Arkansas basin outside the Rocky mountains, comprises about 3,000 feet of shales, and they hold

their argillaceous character so well in approaching the base of the mountains as to warrant the belief that the shore of the sea which received them lay still farther west. They are essentially an off-shore or open sea deposit. The tepee cores are restricted to a zone four or five hundred feet thick occurring about midway in the shale series. The shale of this zone is pale to medium gray in color, is distinctly argillaceous in

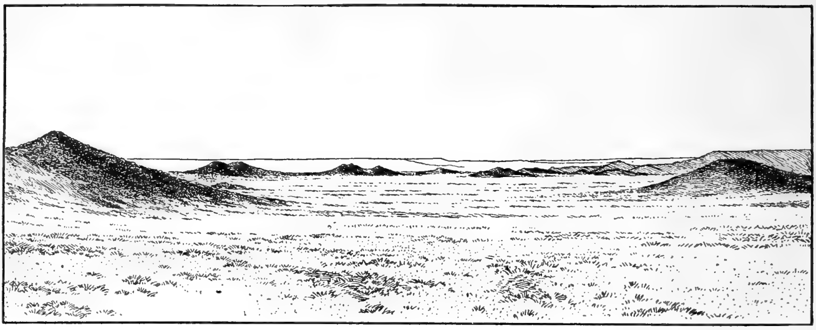

FIGURE 1.—*Group of Tepee Buttes.*
Drawn from a photograph.

type and is finely laminated. It contains also somewhat abundant calcareous concretions which are arranged in horizontal rows.

### *DISTRIBUTION.*

Within the field of our study the tepee zone outcrops as a belt extending from the vicinity of the town of Fountain south-southeast to the Nussbaum mesa, and thence curving to the east. It reaches the Arkansas river near Baxter and follows it to Nepesta, but does not pass south of it. Little Buttes station, on the Denver and Rio Grande railroad, is named from a group of tepee buttes. It is probable that the belt extends farther eastward in the Arkansas valley, and Mr T. W. Stanton reports a few occurrences near Florence and Canyon City where a synclinal basin determines an outlier of the Pierre. As to the further extension of tepee buttes within the Pierre group we have no information.

Within the zone the grouping of tepee cores is irregular, both horizontally and vertically. In places they are so thickly set that hundreds of the resulting buttes may be seen from one point; elsewhere they are solitary or in groups of two or three. Where they abound it is easy to find rows of five or six, but it is equally easy to find rows in other directions, and we were unable to discover any law of arrangement. The distribution of the buttes is further complicated by the fact that part of

the tepee belt is covered by gravels associated with an earlier stage of the degradation of the country, so that the visible buttes represent but imperfectly the distribution of the tepee cores (see figure 2).

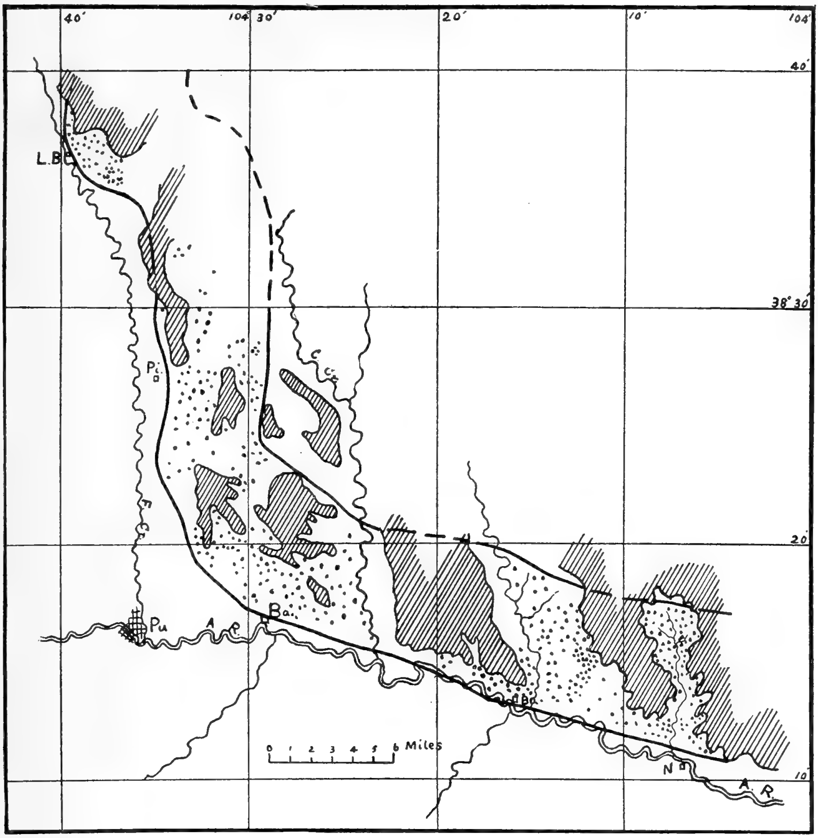


Figure 2.—*Map of the Tepee Zone northeast of Pueblo, Colorado.*

Dots = tepee buttes; heavy lines = boundaries of tepee belt; shaded areas = gravel; AR = Arkansas river; FCr = Fountain creek; CCr = Chico creek; Ba = Baxter; Bo = Boone; LB = Little buttes; N = Nepesta; Pi = Pinon; Pu = Pueblo.

### *GENERAL FEATURES.*

The height of a core is not known in any instance. As each is gradually laid bare by the degradation of the plain the upper part is broken up and washed away long before the lower is exposed. Occasionally a top is seen and occasionally a base, but in the great majority of buttes an intermediate portion only is exposed. The highest observed vertical

exposures measure 12, 13 and 18 feet respectively. The more or less plausible assumption that all members of a certain group have their bases at the same horizon leads to the inference that one of them was originally more than 30 feet high. The observed facts would consist with a general height of 25 feet, and perhaps equally well with a general height of 100 or 200 feet.

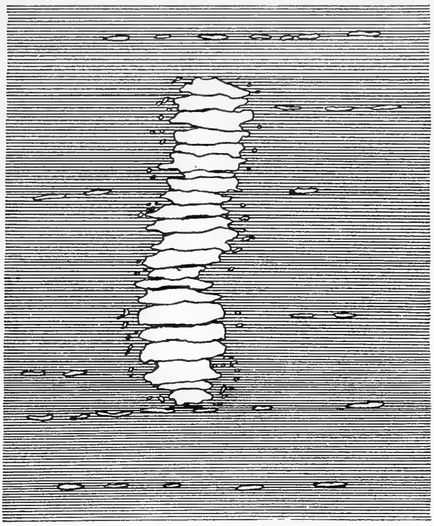

FIGURE 3.—*Ideal Section through Tepee Core.*
Showing relations to shale and concretions.

In horizontal cross-section they are rudely circular or elliptical, the ratio of the axes being seldom greater than 4 to 3. The smallest observed core measures 2 feet across; the largest, 24 by 21 feet. The ordinary diameter is 10 or 15 feet.

While the general form is properly defined as cylindrical, it is far from regular. Wherever part of a side was seen it was found to exhibit shoulders, shelves and overhangs, besides being rugose in detail.

The passage from limestone to shale is abrupt, in the sense that there is no intermediate material sharing the characters of both; but there is a certain amount of interpenetration. Processes of the limestone embrace portions of shale, and the contiguous shale contains outlying lumps of the limestone. The limestone is divided into beds, either completely or approximately, by horizontal partings of shale, so that the best exposed cores have a stratified appearance. The general thickness of these beds is from 1 to 3 feet (see figure 3 and plate 17).

In the shale close to the core are also concretions of a special type, quite different from the ordinary concretions of the Pierre shale. They are but a few inches in diameter, are usually devoid of fossils, and are characterized by smooth processes after the manner of the löss-mänchen.

### *THE TEPEE ROCK.*

The tepee rock is essentially a calcium carbonate, the ratio of calcium carbonate to magnesium carbonate being 18 to 1 in the single sample analyzed. That sample contained also 12 per cent of argillaceous material. For comparative purposes analyses were also made of the inclos-

ing shale and of one of the ordinary concretions of the shale, the determinations showing that the tepee rock does not differ materially in composition from the concretions, and that the argillaceous material is practically identical with the shale. This permits us to regard the argillaceous material as included shale, and therefore an impurity rather than an essential constituent of the tepee rock.

The rock is of coarse texture, breaks with rough fracture, and its general color is a light, warm gray. It is full of fossil shells, and the microscope shows that they are imbedded in a matrix which is composed of fragments of shell, water-worn grains of calcite, foraminifera and clay. Cross-sections of *Lucina* shells show that the original shell structure remains, although the lime of the shell has been recrystallized into calcite. Inside of the shell wall there is a band of radiating crystals of calcite, showing well marked spherulitic structure. The calcareous ooze which must have at first occupied the central cavity of the shell has recrystallized into very pure calcite, leaving the clay impurities at one side of the shell. This central calcite crystal is the same individual which has replaced the lime of the shell, for the two parts extinguish together, the cleavage cracks extend from the center through the outside, and when the spherulitic band is faulted the clear calcite is continuous through the cracks. Experiments showed the spherulitic layer to be slightly less soluble in dilute hydrochloric acid than the clearer calcite.

### *FOSSILS.*

The fauna is marine. By far the most abundant molluscan species is a *Lucina*, and this may indeed be regarded as a leading constituent of the rock. *Inoceramus* ranks second, and cephalopods occur in notable variety. Foraminifers appear in all microsections, and the genera *Globigerina*, *Rotalia*, *Plecanium* and *Saccamina* were recognized. Fossil wood was found in several different cores. The following is a list of the molluscan species as determined by Mr T. W. Stanton:

*Ostrea inornata*, M. and H.
*Inoceramus crispii*, var. *barabini*, Morton.
*Inoceramus vanuxemi*, M. and H.
*Inoceramus sagensis*, Owen.
*Lucina occidentalis*, var. *ventricosa*, M. and H.
*Thetis circularis*, M. and H.
*Anchura* (*Drepanochilus*) *americana*, E. and S.
*Nautilus dekayi*, Morton.
*Baculites ovatus*, Say.
*Baculites compressus*, Say.
*Scaphites nodosus*, Owen(?)
*Scaphites nodosus*, var. *quadrangularis*, M. and H.
*Scaphites nodosus*, var. *brevis*, Meek.
*Ptychoceras crassum*, Whitfield.

*Heteroceras* (*Exiteloceras*) *cheyennense*, M. and H. (?)
*Heteroceras* (*Didymoceras*) *nebrascense*, M. and H.
*Heteroceras* (*Didymoceras*) *cochleatum*, M. and H. (?)
*Heteroceras*, sp. undet.
*Helicoceras*, sp. undet.

## Allied Phenomena in Canada.

In 1886 Dr Robert Bell,* Assistant Director of the Geological Survey of Canada, found on the Attawapishkat river, inclosed in thinly bedded limestones of Devonian age, a large number of "great, spongy and cavernous" limestone masses, "often occupying the full height of the cliffs," which is about 40 feet. These "masses are largely made up of fossils, although the number of species does not appear to be great, while the thinly bedded interspaces contain but few." The fossil forms are *Meristella*, *Strophodonta*, a trilobite and corals. The numerous islets in the river "appear to consist of single masses." From the sketches by which his description is illustrated we select for reproduction views of a cliff and an islet.

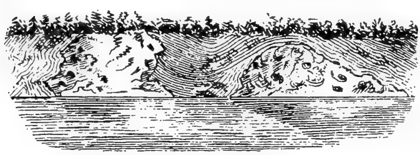

Figure 4.—*Cliff on the Attawapishkat River.* Showing limestone cores of Devonian age. (After Bell.)

Figure 5.—*Islet consisting of denuded Limestone Core.* (After Bell.)

These masses have so many features in common with the tepee cores that their close relationship can hardly be questioned. It is of interest to note, also, that similarity of the topographic features to which they give rise has led observers of the most diverse races to employ the same analogy in the bestowal of names. In a recent letter Dr Bell says:

"I was told that the Indians called the islets (formed of these spongy limestone masses) *wigwams*, and the caverns *doors*, so that your name *tepee* agrees with the name given by our Indians long ago."

## Theories for the Origin of the Cores.

### *CONCRETION THEORY.*

Calcareous concretions are of so frequent occurrence in argillaceous deposits that concretionary action was the first explanation to suggest itself when attention was directed by the senior author to these limestone masses imbedded in shale. It served for some time as a working hypothesis, but gradually became less satisfactory as data were accumu-

* Geol. and Nat. Hist. Survey of Canada, Ann. Rept., vol. 2, 1886, pp. 27 G, 28 G, and 1 plate.

lated, and was finally abandoned. Its rejection was not founded on a knowledge of the essential nature of the concretionary process, for such knowledge we lack, but on the contrast between the characters of the cores and the characters of concretions, especially those occurring in the same formation and at the same horizon. The concretions are wider than high and have smooth spheroidal forms; the tepee cores are higher than wide and are externally rough and irregular. The concretions are fine grained and dark; the cores coarse textured and comparatively pale. The larger concretions are full of crystalline veins, occupying shrinkage cracks; the cores, though much larger than the concretions, are rarely veined. The concretions contain few fossils, and those are chiefly chambered shells and *Inoceramus;* the cores are composed almost entirely of shells and their fragments, with *Lucina* most abundant.

### *SPRING THEORY.*

The cylindrical form of the cores suggested that they were built by calcareous springs, for in the Pleistocene lake Mono lofty towers of tufa were constructed in this way.* This theory was under consideration during the examination of a large number of cores, and special search was made for the concentric structure observed in the Mono deposits. A few features were noted which might belong to such a structure, but in general the search was unsuccessful. Moreover, the horizontal partings of shale seem to show that the core was not built up faster than the surrounding muddy bottom. If there were springs their calcareous contribution was probably so small that it served only to promote locally the growth of shell-secreting animals.

### *COLONY THEORY.*

The abundance of shells in the cores and their relative scarcity in the surrounding shale and its concretions cannot be explained by assuming a difference in the conditions of preservation. It is, indeed, true that such fossils as are contained in the shale are destroyed in the process of weathering, so that collection is difficult, but in the unweathered shale they are quite perfect, even the nacre being retained. There need, then, be no question that their relative abundance in the cores is a phenomenon of original deposition, and the simplest conceivable mode of original deposition is by the direct action of the animals to which the shells belonged. Following this line of thought, we have imagined that each tepee core was the site of a colony of *Lucina*, and that the remains of each perishing generation furnished in some way conditions favorable to the life of the next. The theory requires that the conditions be very favorable indeed, for otherwise a colony could not be expected to hold

* Geological History of Lake Lahontan, by I. C. Russell. Monograph xi, U. S. Geol. Survey, p. 221.

the same site during the long series of centuries needed for the building of a core many yards in height. On the other hand, the conditions could not have been essential to the existence of the *Lucina*, for the same species is occasionally found in the shale. The local conditions actually afforded by a tepee site must have included (1) a tract of firm bottom several yards in extent, and (2) the dead bodies of *Lucina;* but ignorance of the life history of *Lucina occidentalis* makes it impossible to say that these conditions were favorable to it. It is said that modern species of the genus live in colonies and bury themselves, except the siphon, in sand or mud.

Professor Shaler suggests that the Pierre *Lucina* may possibly have spun a byssus and thus utilized a firm support. The development of the recent *Lucina* has not as yet been studied, so we do not know whether at any stage it is attached, but a byssus has been found in the young of *Mya arenaria** and also in *Pecten*,† where the byssus stage varies in different species, and these cases of larval byssal attachment in other families, where such attachment was unknown until recently, would suggest the possibility of a byssus in *Lucina.*

#### *POISON THEORY.*

Another suggested hypothesis ascribes to the tepee site some noxious property by reason of which visiting mollusks were killed and thus made to deposit their shells. A poisonous gas might slowly escape from a buried source or poisons might arise from the decomposition of dead tissues. In such case one would expect nomadic shells to be most frequently victimized instead of the sedentary *Lucina.*

#### *CONCLUSION.*

Of these various explanations the hypothesis of colonies seems to encounter least difficulty; but our present knowledge is not sufficient to establish it.

### THE BUTTES.

#### *CONDITIONS AFFECTING DISTRIBUTION.*

Within the tepee belt the sites of cores are marked by buttes wherever the shale is exposed. Where the shale is capped by gravel deposits, even if thin, the cores are not seen. This relation is readily understood. The gravels represent epochs during which the controlling baselevel was approximately constant, when the streams meandered freely and by lateral

*John A. Ryder: On the Metamorphosis and Post-larval Stage of Development of the Oyster. Rep. U. S. Fish Commission, 1882.

R. T. Jackson: Phylogeny of the Pelecypoda, the Aviculidæ and their allies. Memoirs Boston Soc. of Nat. History, vol. iv, 1890, p. 374.

† R. T. Jackson, op. cit., pp. 340 and 344.

corrasion graded soft shale and hard cores alike to even plains in the valleys. More recently the main streams have sunk their channels to lower levels and their valleys have been broadened by the minor drain-

FIGURE 6.—*View of Tepee Butte.*
Drawn from photograph.

age, laying bare the shale. The soft rock thus exposed is being degraded so rapidly that the degradation of the cores can keep pace with it only

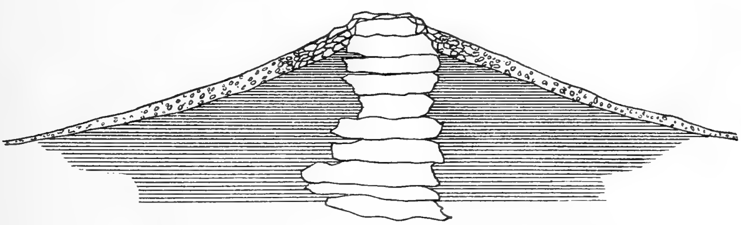

FIGURE 7.—*Ideal Section of Butte represented in Figure 6.*

by the aid of high declivity. The equilibrium of attack and resistance thus maintains high declivity at and near the cores.

### *CONDITIONS AFFECTING FORM AND SIZE.*

Examination of the butte summits shows that the limestone is disintegrated primarily by fracture, and the cause is doubtless found in changes of temperature, including frost. The exposed top of the core is usually shattered and large fragments lie on adjacent slopes. Lower down are progressively smaller fragments, and the external part of the conical mass is evidently a talus of limestone and shale debris. Beneath and protected by this is a conical annulus of undisturbed shale surrounding the core (see figure 7), but it is probable that the form of the butte depends almost exclusively on factors affecting the disintegration and transportation of the limestone debris. Among these must be reckoned frost, heating and cooling, wetting and drying, rain-beating, wind erosion, solution, burrowing and the mechanical and chemical action of roots. Unless some one factor can be shown to dominate the rest, it will be a matter of great difficulty to analyze the process by which the concave

talus profile is produced. The absolute steepness of the slopes is doubtless a function of the rate of the general degradation of the surrounding surfaces. The height of each butte depends partly on the rate of degradation and partly on the cross-section of the core, being greater as the rate is rapid and the core large.

The buttes are commonly from 25 to 35 feet high, and the largest observed, in an embayment of the gravel bluff northwest of Nepesta, measures 75 feet.

### *COMPARISON WITH BUTTES OF OTHER ORIGIN.*

The term butte is ordinarily applied to steep-sided hills with narrow summits. More rarely it has been employed to designate mountains, as "Shasta butte," but this use is probably obsolescent. Taking the word in its narrower sense, we may contrast the tepee butte with neck, dike, cinder, spring and mesa buttes.

The butte marking the site of a volcanic neck, as, for example, Cabezon butte, New Mexico, resembles the tepee in that it is occasioned by a hard, cylindrical core. It differs in the material of the core.

The dike butte also has a hard core, but this core has the form of a vertical plate rather than of a cylinder, and hence the butte is elongated. Example: Bird Tail butte, Montana.

The cinder butte may have a hard core, but does not owe its form thereto. It is essentially a constructional feature, and when freshly formed has a crater at top. Example: Sunset butte, Arizona.

The spring butte, formed by deposition from the water of geysers or other springs, may resemble the tepee core in composition, but is a constructional rather than a degradational feature. Example: Soda butte, Idaho.

The mesa butte, being the remnant of a tabular outlier, is carved, like the tepee butte, from a greater mass, but it has a hard cap instead of a hard core, and thus its form is flat topped instead of conical. Example: Haystack butte, Colorado.

### Acknowledgments.

The investigation of the tepee buttes was incidental to the official work of the United States Geological Survey, and this paper is published by permission of the Director.

The chemical analyses were made by Dr W. F. Hillebrand, chemist of the United States Geological Survey, and the fossil mollusks were determined by Mr T. W. Stanton, paleontologist of that bureau.

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# DISCRIMINATION OF GLACIAL ACCUMULATION AND INVASION

BY WARREN UPHAM

*(Read before the Society December 28, 1894)*

CONTENTS



## ICE-SHEETS AND THEIR ACCUMULATION.

### *VIEWS OF OTHERS AND OF THE AUTHOR.*

In writing of the history of the Ice age, the growth and culmination of the ice-sheets, and their action in eroding, transporting and depositing the glacial drift, terms have been often used which imply or definitely assert an advance, incursion or invasion by the border or somewhat steep front of the ice, extending itself thus over new territory. In North America, especially where the ice-covered area at the maximum stage of glaciation was about 4,000,000 square miles, the language of glacialists frequently brings before us a picture of a thick ice-sheet amassed by snowfall upon its central areas of outflow in Canada, as on the Lauren-

tide highlands north of the Saint Lawrence river, over the basin of James and Hudson bays, on the country extending westward to the Athabasca, Reindeer and Winnipeg lakes, and west of the Rocky mountains on the northern half of British Columbia, becoming upon these tracts so thick that its borders advanced outward, invading the northern United States, and reaching the extreme limits of their farthest incursion along the southern boundary of the drift. According to this view, an ice invasion or two or more invasions at successive times extended the thick land ice of Canada southward hundreds of miles to the Missouri and Ohio rivers, the advance of its border being attended with all the exceptional conditions of glacial erosion and deposition which prevailed upon a belt several or many miles wide next to the ice margin and along that terminal line.

Instead of this view, it is the purpose of the present paper to call attention to evidences that the ice-sheets were principally accumulated by snowfall on all their area, coming into existence as the snow of a great winter storm spreads its white mantle simultaneously over the northern United States and Canada. Such snowfall, not wholly melted away in the summers and preserved with increasing depth during centuries and thousands of years, is here regarded as the origin and cause of growth of the ice-sheets throughout all their extent. To this source of ice formation and increasing supply the outer portions of the ice-sheets were probably due in only slightly less measure than their inner and central portions. During the time of accumulation of both the North American and European ice-sheets the precipitation of snow by storms sweeping over them was doubtless greatest on their windward borders to a distance of 100 or 200 miles inward from the margin of the snow-covered area—that is, upon the belt which the storms passed over during their first three to five or ten hours after leaving the sea or land and coming on the snow and ice. Enough precipitation, however, took place farther on to build up the central areas of the ice-sheets higher than their peripheral tracts, and so to produce an outward flow of the ice on all sides toward its margin, with erosion and transportation of drift from even the central districts to the boundaries. As the rate of ice accumulation was greatest not far back from the edge, the rate of glacial outflow and the slopes of the ice surface there were likewise greater than upon its central tracts.

### *THIN MARGIN AND LOW GRADIENTS OF THE ICE-SHEETS.*

That the outer parts of the ice-sheets were not brought by an incursion but were amassed by snowfall is indicated by the evidences of their gradual attenuation. The extreme limits of the North American and European glacial drift are generally marked by no conspicuous morainic

accumulations, but the volume of the drift diminishes and ceases with an attenuated and often indistinctly defined margin. This condition seems referable to a gradually decreasing power of the ice to carry forward the drift to its margin, on account of the thinness of the ice there and the low gradient of its surface slope. Accumulation by snowfall is, therefore, more probable than an incursion of thick ice flowing onward over new ground as the method of growth of these outer parts of the ice-sheets.

### *EROSION, TRANSPORTATION AND DEPOSITION OF DRIFT BY THE ICE-SHEETS.*

The bed-rocks on the marginal areas of thinly attenuated drift have suffered little erosion. In the states of Ohio, Indiana, Illinois, Iowa, northern Missouri, and eastern Kansas and Nebraska, the great area of the outer and older drift on that central part of the basin drained by the Mississippi river has yielded a much less amount of drift than the country farther north. Upon large tracts no glacial striæ are preserved by the bed-rocks, which seem on the average to have lost scarcely more by ice erosion than their mantle of preglacial valley deposits and the residual clays left by the processes of preglacial rock-decay on the higher lands. Drift transportation and deposition, rather than erosion to obtain additional drift, were the chief work of the ice-sheet in that region. When the ice accumulation by snowfall attained a thickness of several hundred feet 10 to 30 miles back from its boundary, increasing northward to thousands of feet on the region of the Laurentian lakes, northern Minnesota and Manitoba, its currents carried away much drift from the last named areas of plentiful rock erosion and deposited it on the broad plain country covered by the comparatively thin ice accumulation in the Mississippi basin.

### *FORMATION OF MORAINES.*

After a considerable retreat of the ice-border had taken place under the warm climate which brought the Glacial period to its end, very different conditions of ice action prevailed. Instead of the mostly smooth and even surface of the earlier drift, the later and more northern drift was deposited with much unevenness in its general contour, enclosing multitudes of lakes in its hollows, and including numerous approximately parallel or irregularly interlocking series of marginal drift accumulations called moraines. These belts of hilly drift seem to mark stages when the glacial recession was temporarily interrupted by halts or slight readvances of the generally waning ice-border. The high altitude of the ice-sheet forbade extensive melting upon the greater part of its area, but the warm climate of the Champlain epoch rapidly melted its borders, producing

there a much steeper gradient of the ice-front, and consequently more vigorous action in the deposition of the general drift sheet and in amasssing marginal moraines than when the earlier drift was deposited.

### *LOCAL ALPINE OR DISTRICT ICE-SHEETS AND GLACIERS.*

In the Cordilleran mountain belt of the western United States many large areas of alpine ice-sheets and glaciers have been found from the boundary of the great northern sheet of glacial drift along distances of from 700 to 800 miles south. Similarly the glaciation of northern Europe was accompanied by a great extension of glaciers in the Alps, the Caucasus belt, the Pyrenees, and other mountain tracts of France and Spain. These areas had increased snowfall and their glaciers grew by its accumulation, and the same conditions appear to have been sufficient to produce the full extent of the contiguous continental ice-sheets.

As the mountainous coast of Greenland has many local ice-caps of only a few miles extent, with outflowing valley glaciers close to the border of the inland ice-sheet, and as the zone of predominant wastage by ablation on that ice-sheet reaches only 10 to 20 or 30 miles inward from its edge, so I believe that the vast continental ice-sheets of Pleistocene time grew by accumulating snowfall upon nearly all their expanse. The Glacial epoch of their growth was soon succeeded by the Champlain epoch of their departure, when the great Pleistocene winter ended with a general change to a long secular springtime and rapid retreat of the ice-sheets, scarcely less remarkable than their time of growth.

### *PROBABLE CAUSES OF ICE ACCUMULATION AND DEPARTURE.*

*Ice Accumulation attributed to high Land Elevation.*—This conclusion, that the ice came upon all its area principally by snowfall, is in accord with the explanation of the causes of the Glacial period by great epeirogenic uplifts of the countries which became glaciated and drift-covered. We need not here recount the evidences of the elevation of the drift-bearing regions as high plateaus, raised above their present altitude from 2,000 to 3,000 feet or more, as known by the depth of submarine river valleys on both our Atlantic and Pacific coasts and by the northern fiords. The Sogne fiord, the longest and deepest in Norway, has a maximum sounding of 4,080 feet, and this probably measures approximately the epeirogenic uplift, which at its culmination caused the envelopment of some 2,000,000 square miles of northern Europe and the present adjoining sea beds by a vast sheet of land-ice. The altitude of the glaciated areas of both these continents appears to have been sufficient to cause their precipitation of moisture to be snow throughout the year, amassing the ice on nearly the whole country which it covered with its drift. Only

on exceptional tracts, displaying unusual evidences of pressure by an advancing ice-sheet, need we appeal to such an invasion instead of the more gradual, slow and gentle process by snow accumulation.

*Ice Departure attributed to Land Depression.*—Beneath the weight of the ice-sheet the formerly elevated land sank to its present height or mostly somewhat lower, so that when the ice melted away the sea covered coastal portions of the drift-bearing countries. A moderate subsequent reëlevation has since raised the fossiliferous marine beds which were deposited over the glacial drift upon these coastal tracts to altitudes having a maximum of from 500 to 600 feet in both Canada and Scandinavia above the present sealevel. The change of climate resulting along the borders of the ice-sheet on account of land depression caused rapid melting there, and this advanced inward until all the ice disappeared. The depression from the former high altitude, as Dana remarks, would transfer the southern part of the ice-sheet from a climate like that of Greenland to the temperate climate of southern Canada and the northern United States. Marginal melting then gradually pushed back the boundary of the ice and thus gave to its front an increased steepness of slope, whereby any slight halt or readvance due to a series of years of unusual cold and snowfall became recorded in a marginal moraine. Mainly, however, the temperate climate due to the subsidence of the land prevailed over the accelerated currents with which the ice flowed outward to its steeper border, so that, although the ice-action was then most vigorous, it was almost continually being restricted within diminishing limits, and finally the drift-bearing regions became wholly uncovered.

## Invasion by the advancing Border of an Ice-sheet.

### *THE ADVANCE NOT CONTINUOUS.*

On some parts of the boundary of the glacial drift in the United States terminal moraines were formed at or near this farthest limit of the ice-sheet, contrasting remarkably with the recession of the ice mostly 50 to 200 miles back from its early outer limits in the greater part of the Mississippi basin before its moraines there were formed. The warm sunshine and rains of the temperate climate due to the land depression had melted the ice away upon an area of more than 100,000 square miles in the Mississippi basin before the stage of the formation of the moraines, which in that region, as already noted, seem readily explained by the steeper slope then presented by the mostly waning but now and again temporarily halting or slightly readvancing ice-border. Farther eastward, however, as on the east side of the Wisconsin driftless area, and along or near the limit of the ice-sheet and glacial drift for the whole distance

of 700 miles from the Scioto river in Ohio eastward to Marthas Vineyard and Nantucket, where this boundary passes into the Atlantic ocean, series of moraines, continuous with those of the upper Mississippi region and of the same general age, form the outer margin of the drift or are nearly coincident with that margin but distant from one or two to 15 or 20 miles back from it. All these moraines, whether situated far back from the glacial boundary or near to it or upon it, give good evidence, by the volume and contour of their drift accumulations, that the ice-border while forming them halted in its recession and usually made at least some slight readvance or invasion of territory which it had relinquished or which even in some districts it never before had occupied.

### *ATTENDANT DRIFT EROSION, TRANSPORTATION AND DEPOSITION.*

The country inclosed by the moraines has been powerfully eroded by the ice, its striæ being found upon practically the entire rock surface. Large accumulations of drift, which I think to have been almost wholly englacial during the time of that erosion, being held and carried forward in the lower part of the ice-sheet, perhaps to the height of a quarter of its whole thickness, are spread over the strongly glaciated bed-rocks, and much of this drift is amassed in steep, irregularly grouped hills of exceptionally bowldery drift, extending in belts one to five miles or more in width. These moraines, here parallel, there interlocking or overlapping one another, are traced in a complex series from Manitoba and the Dakotas east to Long island, New England and the Atlantic.

On the smooth areas of drift beyond the moraines in the Mississippi basin the proportion of the ice inflowing from the north and bringing the bowlders and finer drift derived from the granitic, gneissic and other crystalline rocks of northern Wisconsin and Michigan, of Minnesota, and of Canada, may have been a tenth or less, or a fourth or a third part, of all the ice covering those areas. That the northern ice was much less than the amount supplied by the snowfall seems demonstrated by the attenuation of both the ice and its drift. It was not, as I believe, an ice invasion, but mainly snow and ice accumulation, with a proportionally small inflow of northern ice, bringing the greater part of the drift. The glacial currents were too feeble to accomplish much erosion, and most of the englacial drift borne in by the ice currents from the north was probably laid down as subglacial till during the time of culmination of the ice-sheet and while the ice was finally retreating.*

In the drift areas bordered by the moraines, upon which, indeed, the ice-front doubtless bodily moved forward, as a general rule, for short distances while amassing the morainic hills, the steep frontal slopes and

* Bull. Geol. Soc. Am., vol. 5, 1894, pp. 83, 84.

vigorous glacial currents enabled large portions of the englacial drift to be carried to the glacial boundary and heaped in these hills, knolls and irregular ridges; other portions formed the kames and eskers; and a considerable stratum of the general till-sheet appears to have been englacial and at last superglacial when the rapid ablation bared the land surface and permitted that part of the drift to fall upon it as the upper division of the till.

*DISPLACEMENT AND FOLDING OF SOFT UNDERLYING BEDS.*

Closely associated with the outermost moraine along a distance of more than 200 miles on Staten and Long islands, Block island, Marthas Vineyard and Nantucket, the soft Cretaceous and Tertiary strata underlying the morainic drift have been more or less disturbed, being seen in many sections to be pushed into anticlinal and synclinal folds parallel with the course of the moraine. Mr Arthur Hollick, in a paper read before the last summer meeting of this Society, accounts for this displacement and folding by the great pressure of the ice-sheet at a time of its bodily advance by which the moraine was amassed.* In this conclusion he agrees with the earlier statement of the same explanation by F. J. H. Merrill for sections observed by him on Long island,† and with the present writer for the remarkably folded strata of Gay Head, at the west end of Marthas Vineyard, and for the less inclined early Pleistocene fossiliferous marine beds under the moraine in Sankoty head, on the east shore of Nantucket.‡

These disturbances of soft and easily dislocated beds beneath the drift of an ice incursion are equalled or perhaps surpassed by the dislocation, crumpling and infolding with glacial drift, which similar underlying strata display on the islands of Möen and Rügen, in the southwest part of the Baltic sea. Doubtless there, as on our Atlantic coast, the ice-front advanced, and the very irregular displacements and folds are effects of its disrupting power.

When any ice incursion took place upon harder rocks, as in the country westward from Staten island to the driftless area of Wisconsin, the pressure in many places may have been equally great, but it was expended in eroding, planing and striating the bed-rocks, as they are found everywhere within the limit of the outermost prominent moraines. The extent of the ice advance, however, which formed these moraines and produced the folds of the soft strata eastward and the glaciation of the bed-rocks westward, may probably have been no more than a few miles or

* Bull. Geol. Soc. Am., this volume, pp. 5–7; more fully published, with sections of the distorted and folded beds, in Trans. New York Acad. Sci., vol. xiv, October, 1894, pp. 8–20.

† Annals of the New York Acad. Nat. Sci., vol. iii, 1886, pp. 341–364, with sections and map.

‡ Proc. Bost. Soc. Nat. Hist., vol. xxiv, 1888, p. 139.

rarely perhaps 10 or 20 miles. A much farther extension of new drift over an old drift surface by gradual snow and ice accumulation, with some glacial inflow from the north, is known in Ohio, Indiana and Illinois, and especially in northeastern Iowa, where a forest bed between the successive till deposits has been mainly preserved, undisturbed by erosion during the later ice accumulation, upon large areas reaching 10 to 30 miles or more back from the margin of the newer drift.

## Irregularity of glacial Invasion and its meteorologic Explanation.

From my exploration of the moraines and other drift deposits of the Minnesota lobe of the ice-sheet, it is learned that, while the south end and western side of this ice-lobe were being melted back from the first or Altamont moraine to the fifth and sixth or Elysian and Waconia moraines, its eastern side became absolutely or relatively thicker than before in comparison with the ice outflowing southwestward from the Lake Superior area. The southeastward and eastward currents of the central part of the lobe therefore pushed back the southwestward currents, so that the gray and blue drift from the Cretaceous shales of western Minnesota and from the Silurian limestones of Manitoba was spread over the red drift derived from the Cambrian and Keweenawan sandstone and eruptive rocks of the Lake Superior basin. An overlap of the gray drift, with much limestone, above the red drift, containing no limestone, is observed along an extent of fifty miles from Wright and Anoka counties northeastward to the Saint Croix river on the boundary of Wisconsin.*

At a somewhat earlier time, preceding and during the formation of the Altamont moraine, while much melting and recession of the ice-sheet were taking place in Iowa, South and North Dakota and southeastern Minnesota, with rapid deposition of loess, the ice border on the east side of the Wisconsin driftless area appears to have increased in thickness and to have encroached at least several miles on that area, covering ground which had not previously been glaciated.

During the same time and later, while the ice-sheet in the upper Mississippi basin and the region of the Laurentian lakes eastward to lake Nipissing and the east end of lake Erie was melting away, its southern border farther east still reached approximately to its early maximum limits, and in certain portions, probably including the whole extent of Long island, Marthas Vineyard and Nantucket, there was apparently an advance somewhat beyond the earlier boundary.†

* Proc. Am. Assoc. Adv. Sci., vol. xxxii, 1883, pp. 231–234. Geology of Minnesota, vol ii, 1888, pp. 254–256, 409–413.

† Bull. Geol. Soc. Am., vol. vi, p. 26, November, 1894; Am. Jour. Sci., iii, vol. xlix, pp. 1–18, with map, January, 1895.

Doubtless the prevailing course of storms during the Glacial and Champlain epochs, as at the present time, was from west to east and northeast. With the restoration of a temperate climate by the subsidence of the land to its present height, or mostly somewhat lower, the sunshine and rains began to melt the ice away. Its border in general retreated and became steeper, but with interruptions, ranging in length from decades to centuries, when the snow accumulation and ice outflow caused important extensions of the glaciation. The warm air currents, bringing rainstorms and therefore rapidly melting the front of the ice where they first swept over it at the west, would, however, be chilled as they passed onward, giving principally snowfall on more eastern parts of the ice margin. The western ice-melting also contributed much to the supply of moisture for this snowfall from the eastwardly moving storms.

Instead of receding along all its extent the front of the North American ice-sheet appears thus to have remained nearly stationary or to have advanced in its great lobe from Salamanca, in southwestern New York, to Long island and Nantucket, and probably onward in the eastern provinces of Canada, during the time of the mainly rapid melting and departure of the ice upon its extensive windward area from the Dakotas and Iowa east across lakes Superior, Michigan, Huron and Erie, which then were united in the glacial lake Warren. The retreat of the ice and the accompanying uplift of the land from the Champlain subsidence here passed from southwest to northeast, so that northern New England was the latest part of the United States, at least eastward from the Rocky mountains, to be uncovered from the ice-sheet and elevated to its present height.

## Criteria of Ice Accumulation and Invasion.

Near the margin of drift-bearing areas, glaciation chiefly due to snow and ice accumulation, with less supply by inflow from central and thicker tracts of the ice-sheet, is indicated, as the present writer thinks, by a gradual attenuation of the drift, absence of morainic knolls and hills, and scanty glacial erosion of the bed-rocks.

Conversely, the evidences of an invasion by the ice-sheet upon its marginal tracts consist in thick drift deposits, hilly morainic belts, and much planing and striation of the rock surface. Displacement and folding of soft strata beneath morainic deposits seem to be especially conclusive proof of vigorous incursion by a steep ice-front.

Readvances of the ice within its drift area may be recognized by very clearly defined belts of morainic hills, pushed out on smooth tracts of till, or by the very rare occurrence of disrupted or deeply crumpled underlying beds. In most cases where moraines belonging to the time

of general glacial recession are conspicuously hilly on their outer side, they record some readvance, rather than a mere halt or a slackening in the rate of retreat.

The origin of continental ice-sheets by gradual accumulation from snowfall upon nearly their entire areas, without extensive bodily advances of their borders, can be best referred, as the writer believes, to high epeirogenic uplifting of the regions which became thus ice-clad. These uplifts probably also affected, in a less degree, large areas outside the limits of the ice-sheets and drift. The central parts of the glaciated area of North America were apparently raised higher than its borders, and in some instances streams formerly flowing northward may have been then turned to the south, as Carll, Spencer, Chamberlin and Leverett have shown for tributaries of the Allegheny and Ohio rivers. During the epoch of high elevation and the Ice age in which it culminated, these streams and all others flowing from the uplifted area were cutting down their channels at a much faster rate than during the Tertiary era of lower altitude and less slope. As the ice-sheet grew in only comparatively slight degree by invasion, it was not probably an efficient agency for the formation of glacial lakes and deflection of rivers from their present courses during the oncoming of the Glacial period. With the first envelopment of the country by snow and ice, a continually cold climate appears to have begun and thence to have lasted through the time of the ice accumulation, excepting marginal fluctuations of probably not very great extent, either in area or time, as compared with the ice-covered area and the duration of the Ice age.

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# GLACIAL LAKES OF WESTERN NEW YORK

BY H. L. FAIRCHILD

*(Read before the Society December 28, 1894)*

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## General Statement.

### *TOPOGRAPHY OF THE "FINGER LAKES" REGION.*

To American geologists the geographic features of the "Finger lakes" region are too well known to require extended description. For the purpose of this writing it will be sufficient to briefly state the relation of the lakes to the land lying immediately to the southward. These lakes, from Conesus, on the west, to Otisco, on the east, occupy deep valleys of generally north-and-south trend, and of preglacial origin. The valleys all have free drainage northward, but southward they terminate abruptly in the high land which forms the divide between the waters of the Saint Lawrence and the Susquehanna rivers. This elevation is a plateau of Portage-Chemung strata, deeply incised by the river erosion of the long ages preceding the Glacial period. The front of the great ice-sheet lingered at the northern limit of this plateau, and lobes of the retreating ice occupied the old north-and-south valleys and left them half filled with frontal moraine drift.* It is this drift which forms the water-parting or col in all these valleys.

### *ORIGIN OF THE GLACIAL LAKES.*

As the glacier-lobes succumbed to the melting and retreated northward the spaces between the ice and the deserted moraines were occupied by

*A description of the moraines in these valleys is given in Professor Chamberlin's article entitled "Terminal Moraine of the Second Glacial Epoch," in the Third Ann. Rep. U. S. Geol. Survey.

water, overflowing southward. A preliminary description of these ice-dammed lakes is the purpose of the present writing.

These glacial lakes, the predecessors of the present "Finger lakes," were vastly larger than their successors, and of more than twice their depth. Those described in detail in this paper were all forced to pour their overflow into the southern Susquehanna drainage. Ice-dammed lakes also occupied many valleys in which today no water is ponded. This was probably the case with the upper valley of the Genesee river and with the two stronger valleys adjacent to either side of the Genesee. There were two valleys in similar relation to Canandaigua lake, with several valleys east and others west of the area under consideration, and probably other less important elevated valleys which held glacial lakes.

Some of these lakes have a complicated history and their relationships are somewhat intricate. By the northward retreat of the ice-wall new and lower outlets were opened, the directions of flow were thus changed, the water bodies were dismembered and the differentiated waters at successively lower levels had varying relations.

## *EVIDENCES.*

The descriptions of several extinct lakes, given later, will present inductively the proofs of the former existence of such elevated waters, but the argument and evidences may here be summarized as follows:

1. Theoretical considerations. Granted a sheet of glacial ice or ice-lobes filling the valleys, the southern margins retreating by melting, and it must be admitted, unless the capacity of ice to serve as a dam be denied, that the uncovered north-sloping southern ends of the valleys would fill with water.
2. Lacustrine silts in the valleys, enclosing materials dropped from floating ice.
3. Shoreline markings, as sea-cliffs and terraces of wave erosion and wave construction.
4. Abandoned stream channels, with their peculiar conformation and unmistakable characters, south of all the important cols. They are cut out of the ice-drift, and some are strongly developed and of large capacity.
5. Valley-fillings of fluviatile sand or gravel accumulated on lower ground by the old streams.
6. Stream deltas. They furnish the most conspicuous and universal proofs and are most depended upon in this paper for the water altitudes. They are prominent upon nearly every stream emptying into the lake-basins, and their terraces are often visible for miles.

That these deposits of gravel and sand are stream deltas formed in extinct lakes admits of no reasonable doubt. Their relations to present streams, to the valley slopes, and especially to the cols and the abandoned stream channels over the cols afford convincing evidence, which will duly appear in the following pages. The plateaus at the summits of the deltas are above the outlets of their respective lakes. The lower terraces, representing pauses in the subsidence of the waters, are irregular and puzzling, and will be briefly discussed in the description of the Ithaca lake.*

### *TERMINOLOGY.*

It has been necessary to adopt some guiding rule in naming the successive and sometimes tributary lakes. The one chosen is simply to give for each water-body, or different level having a distinct outlet, a separate lake name. No case has yet been found where one body of water had more than a single outlet at one time. To prevent confusion with existing lakes and at the same time to give names which will indicate locality, these ancient local lakes are, with some unavoidable exceptions,† named after the principal towns now located on their sites. For the glacial lakes covering vast areas the practice established by Dr J. W. Spencer and Mr Warren Upham of giving non-geographic names seems most appropriate, but for the smaller local lakes geographic names are desirable.

## Enumeration of the Lakes.

### *PREDICATION OF LAKES NOT STUDIED.*

In the following table 18 extinct lakes are enumerated in geographic order from west to east, but judging from the location and direction of streams, other lakes doubtless existed in several north-and-south valleys lying west of Tonawanda creek, and in several lying east of the Onondaga. The shore phenomena of only a few of these ancient lakes have been examined, as the facts embodied in this preliminary paper are the results of but a few weeks study of the special subject in the hours free from college duties. As to the former existence of several of the lakes named in the table, the statements are based upon personal knowledge of the topography. The predication of lakes numbered 3, 7, 8, 9, 11, 15, 16 and 17 is upon theoretic grounds derived from maps or second-hand information. These will be the subject of future study.

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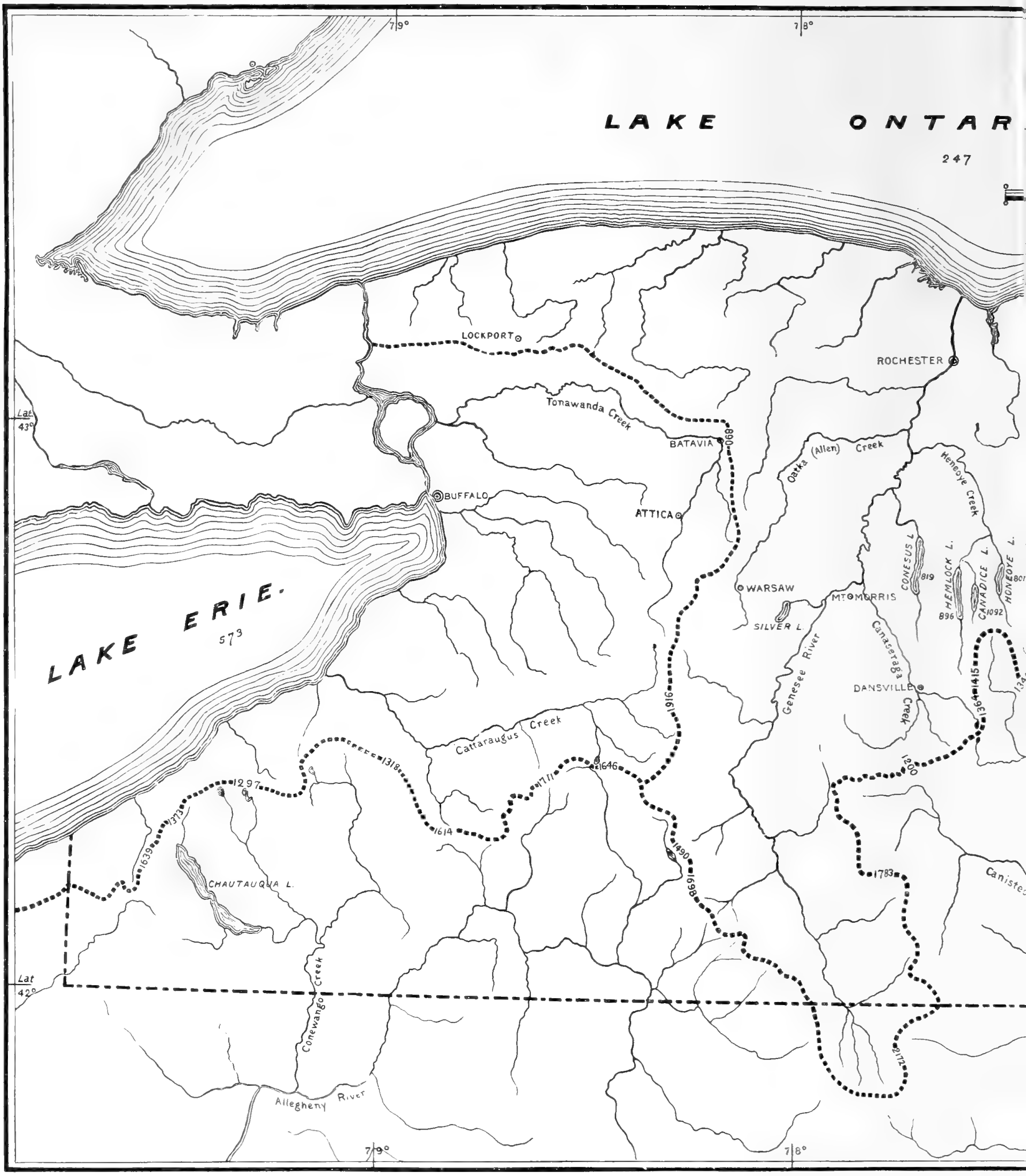
* See page 373.

† These exceptions are numbers 3, 7, 8, 11, 16, 17 and 18 of the table on page 357. The privilege is claimed of changing the names if found desirable.

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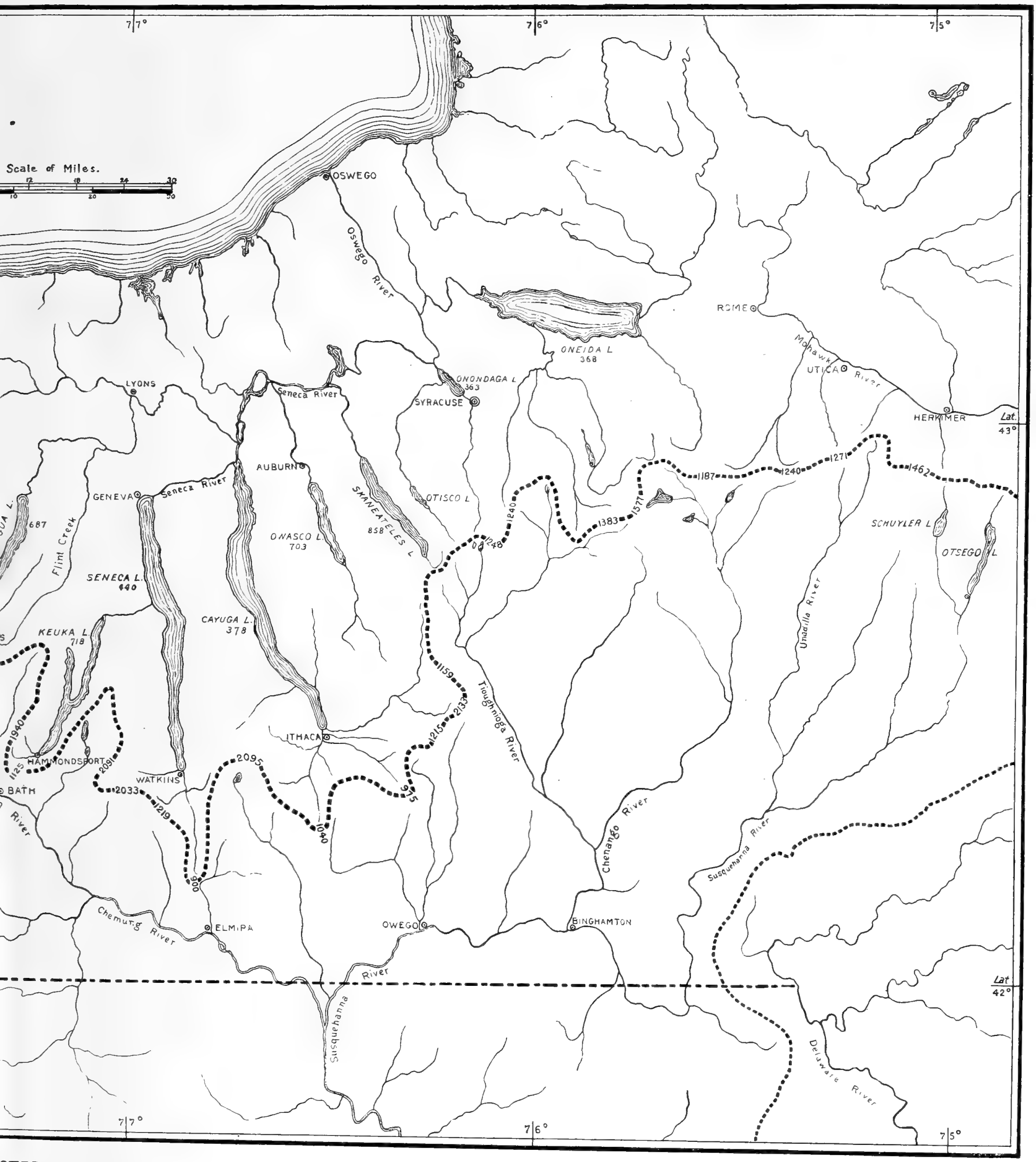


STERN NEW YORK.

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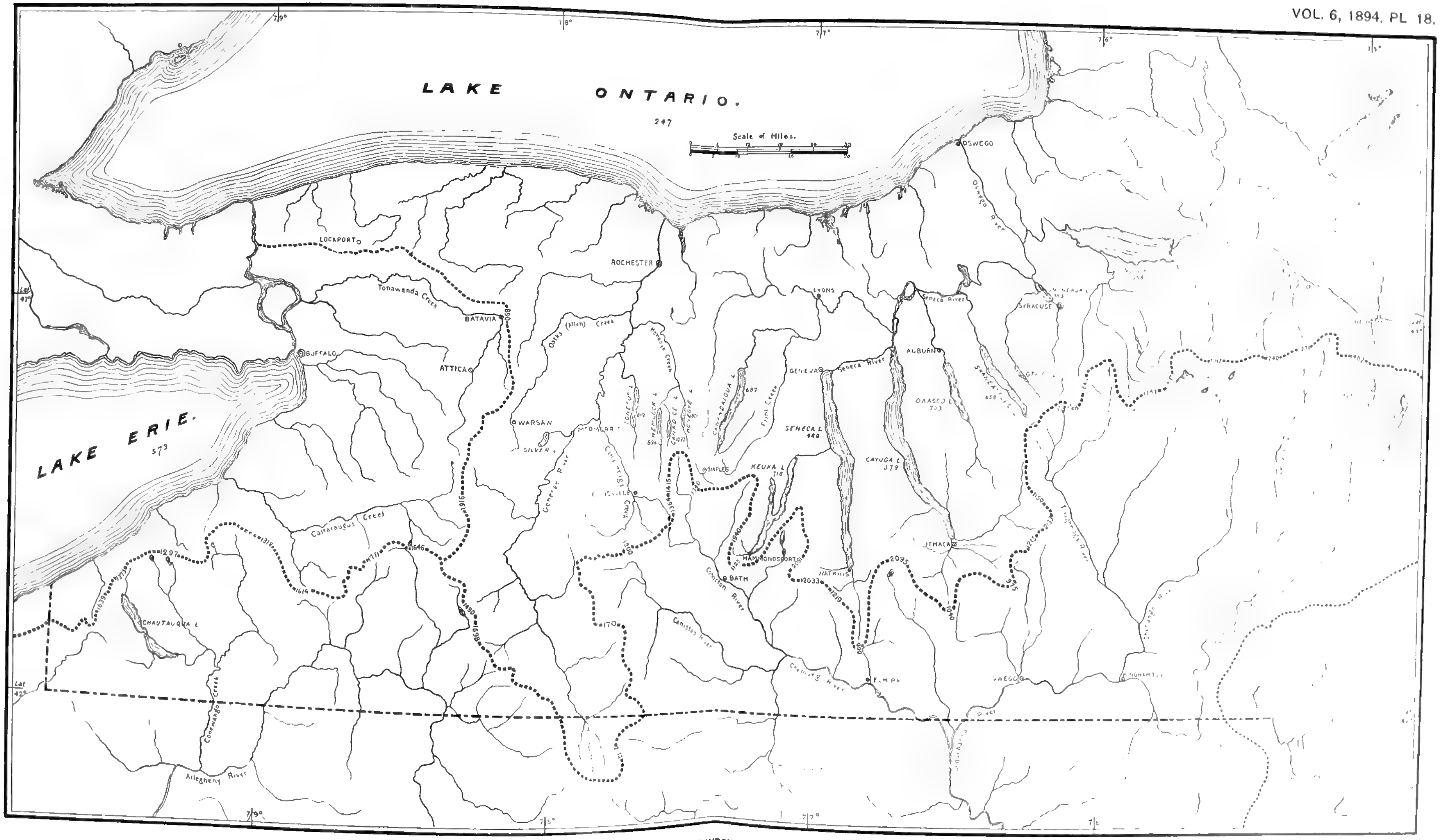


HYDROGRAPHY OF WESTERN NEW YORK.

Water-partings between drainage systems shown by heavy broken lines.
Figures indicate altitudes in feet above sealevel.
The figures placed transverse to broken lines indicate location and altitude of glacial lake outlets.

*TABULATION OF DATA.*

| Names of extinct lakes. | Present lake or stream. | Altitude above sealevel. | | Estimated dimensions. | | |
|---|---|---|---|---|---|---|
| | | Outlet. | Delta summits. | Depth. | Length. | Width. |
| | | | | *Feet.* | *Miles.* | *Miles.* |
| 1. Attica | Tonawanda creek | ...... | ...... | ...... | ..... | ..... |
| 2. Warsaw | Oatka creek | ...... | ...... | ...... | ..... | ..... |
| 3. Genesee | Upper Genesee river | ...... | ...... | ...... | ..... | ..... |
| 4. Dansville | Canaseraga creek | 1,200± | 1,250± | 500 | 24 | 2 |
| 5. Scottsburg | Conesus lake | 900± | 920+ | 150 | 12 | 2 |
| 6. Springwater | Hemlock lake | ...... | ...... | ...... | ..... | ..... |
| 7. Glacial Canadice | Canadice lake | ...... | ...... | ...... | ..... | ..... |
| 8. Glacial Honeoye | Honeoye lake | ...... | ...... | ...... | ..... | ..... |
| 9. Bristol | Mud creek | ...... | ...... | ...... | ..... | ..... |
| 10. Naples | Canandaigua lake | 1,340± | (?) | 800 | 13 | 2 |
| 11. Flint | Flint creek | ...... | ...... | ...... | ..... | ..... |
| 12. Hammondsport | Keuka lake | 1,125 | 1,158 | 600 | 24 | 2 |
| 13. Watkins | Seneca lake | 900 | 961 | 1,000 | 30 | 5 |
| 14. Ithaca | Cayuga lake | 975 | 1,020 | 1,100 | 35 | 6 |
| 15. Groton | Owasco lake | ...... | ...... | ...... | ..... | ..... |
| 16. Glacial Skaneateles | Skaneateles lake | ...... | ...... | ...... | ..... | ..... |
| 17. Glacial Otisco | Otisco lake | ...... | ...... | ...... | ..... | ..... |
| 18. Tully valley | Onondaga creek | ...... | ...... | ...... | ..... | ..... |

*ALTITUDES.*

The figures for altitudes given in the table are mostly from personally conducted spirit-level measurements, using railroad or lake altitudes as datum-points. The determination of accurate heights was the most difficult part of the work. The doubtful figures are marked + or —. They are discussed in the paper and, at the worst, are not far wrong. Allowance must be made for the indefiniteness of the shore phenomena. Those depended upon in this study are chiefly the terraces of deltas accumulated where streams poured into the extinct lakes at high levels, and they represent planes at an uncertain and variable number of feet above the water-surface.

## Description of the Map.

For the accompanying map (plate 18), the United States post-route map of New York has been used as the base. The water-partings between the several hydrographic basins and the smaller streams heading upon the divides have been carefully represented.

The numerals all indicate altitude above ocean level, and are the result of much study and correlation of data. In several cases they supersede formerly recognized altitudes. The altitudes on the divides are in nearly

all cases taken from verified railroad levels, and usually represent the lowest places or notches in the divide. In no instance do they indicate hilltops or extremely high points.

The glacial lake outlets across the divide, which are referred to in this paper, are indicated by placing the numerals transverse to the line of water-parting. These figures give the height of the present bottom of the stream-channel on the col, or the present height of the "waste-weir." Obviously this is considerably below the lake surface.

## The Dansville Lake.

### *CANASERAGA VALLEY.*

The Canaseraga creek flows into the Genesee river at Mount Morris. The lower and main part of the valley extends from Mount Morris south to Dansville, a distance of 15 miles. This valley has a width at the bottom of more than one mile, an altitude above sealevel of about 690 feet, and the slopes rise steeply on either side an added height of from 800 to 1,000 feet. About three miles south of the present village of Dansville the valley is interrupted and deeply filled with drift. Two mature post-glacial valleys originally united here. One of them leads southwest toward Hornellsville and is now occupied by the middle portion of the Canaseraga creek. The other, of less definite character, opens southeast toward Wayland and holds Whiteman and Perkinsville creeks. A fourth, and postglacial stream, Stony brook, flows down from the tableland southward, and has produced one of the finest glens in the state. These four streams join near the village. The preglacial valleys are choked with glacial drift, and south of the moraine-fillings the valleys are half buried under the gravel overwash and the stream deposits. The valley of Conesus lake is connected with the Dansville valley by a cut or transverse valley about 200 feet higher than Dansville.

### *DIVIDES.*

The Delaware, Lackawanna and Western railroad climbs the east side of the valley, being 335 feet above Dansville village, and winding southeast over the moraine to the Cohocton valley, gives us by its summit level the height of the col in the southeast tributary valley. The highest point on the railroad is three-quarters of a mile west of Wayland station, with an altitude of 1,364 feet. This is only five or six miles from Dansville, and the valley bottom here is a comparatively smooth plain.

The col in the southwest or middle Canaseraga valley is near Burns station on the Hornellsville branch of the "Erie" railroad, about ten miles from Dansville. The drift is here smoothed off into a plain, upon which the railroad lies, and the altitude of the railroad station is given

on old profiles as 1,203 feet. This is not at the head of the Canaseraga creek, which has its source some miles further northwest beyond the village of that name.

The ground at and beyond the cols has not been studied by the writer with reference to this subject, and the stream channels of the lake outlets cannot be here described.

### *DELTAS AND WATER-LEVELS.*

The successive levels held by the Dansville lake may be determined not only by the remnants of delta terraces at the head of the main valley, but by those made by numerous brooks pouring down the steep sides of the valley all the way to Mount Morris. The slopes are too steep to preserve any beaches.

The principal level is found at about 1,250 feet. This forms a gravel plateau either side of Stony Brook glen, and the railroad station of that name on the Central New York and Western railroad is located on it. This level is prominent at Conesus village, on the east side of the Conesus basin, and may be seen all about the valley.

The Canaseraga-Stony Brook delta has been cut by both streams to a depth of 200 feet and has been almost destroyed. Between the two streams, however, is left a strip, which toward the delta front is a quarter of a mile wide and a mile long, and gives good lower terraces. The higher levels are too much eroded to be clear, and at one point the strip is only a "hog-back." At 915 feet it is a broad, cultivated plateau, and the terminus is similar, with an altitude of 894 feet (Clark terrace). The altitudes were taken by spirit-level, using as datum-points the railroad levels, which are subject to some revision.

The 894-foot level is found in a well marked terrace on the east side of Stony brook, and can be located at other points. In the side of the strip of delta which is on the property of Anson Whiting, on the west side of Stony brook, is a shelf about 300 feet wide, a quarter of a mile long and at an altitude of 849 feet. A delta-point at Culbertson glen, on the Delaware, Lackawanna and Western railroad, midway between Dansville and Groveland stations, is at 853 feet, and other terraces visible along the steep slopes of the valley seem to be at about this level, which is the lowest well marked lakelevel observed. Lower levels are seen as stream floodplains. The two conspicuous levels in and about the valley are, one at about 1,250 feet, the other ranging above and below 900 feet.

### *LAKE HISTORY.*

*Perkinsville Lake.*—For a brief time a smaller lake must have occupied some part of the southeast branch, with outlet near Wayland into the Cohocton over the col 1,364 feet high. As it covered the site of

Perkinsville, it may be called the Perkinsville lake. The evidences of this highest level have not been studied.

*The main Lake.*—Before the ice had melted back as far as the mouth of the present Stony Brook glen, the Canaseraga tributary valley was the basin of a small lake with its overflow near Burns into the Canisteo creek, which remained the lowest outlet of the enlarged or Dansville lake. This earlier episode of the lake may be called the Poags Hole episode, using the local name applied to the narrow, picturesque middle part of the Canaseraga valley. The lake remained at this level while the ice-dam was melting back at least to Mount Morris, 18 miles from the head of the main valley, and perhaps much longer, or even after it reached the Genesee valley. During this time the other streams above named brought down a great amount of detritus and built large deltas at the south end of the broad valley. These have been spread out over the north slope of the moraine, and being principally fine and incoherent material they have been eroded into forms which resemble at first glance the hummocky, morainic drift. Indeed the larger part of the deltas has been removed, and the remnants are so eroded that the terraces or water-levels are not conspicuous, although clear upon examination. A fine view of the head of the valley is obtained from either the Delaware, Lackawanna and Western railroad or the Central New York and Western railroad, the latter connecting with the former at Wayland.

The altitude of the valley-bottom at Dansville is given by the Mount Morris and Dansville railroad as 691 feet. Hence at its full height the lake was more than 500 feet deep, and this lasted for a time sufficiently long to allow the ice-lobe to recede at least 20 miles.

When the ice-barrier was so far removed as to permit a lower outlet of the waters northward, probably to the northwest by Caledonia and Le Roy, then the middle Canaseraga creek came into existence and the reversed drainage began to fill the valley and eventually joined forces with Stony brook in the building of the delta southwest of Dansville. When the Dansville lake was much lowered the Canaseraga was compelled to reëxcavate its middle valley and has produced the rough and peculiar topography of the narrow, deep gorge, six miles long, which has been locally called Poags Hole. In cutting down near the present mouth of the gorge the stream fell upon an angle of rock projecting from the west side of the great valley, and was compelled to make a rock-cutting which gives a singular postglacial exit to an old preglacial valley.

## The Scottsburg Lake.

### *CONESUS VALLEY.*

Conesus lake is eight miles long and about one mile wide. The valley extends south as a swampy area for more than two miles, and then rises

gradually for nearly two miles more to the village of Scottsburg, which has an estimated altitude of about 900 feet. A small stream, called simply the Inlet, drains the higher, narrow valley south of the village and flows on in a sinuous course to the lake. The only considerable tributary is Conesus creek, from the east, which joins near the lake.

*DIVIDE.*

The bounding walls of the valley are unbroken except at one point. A remarkable depression or postglacial transverse valley severs the western wall at the village of Scottsburg and leads to the Canaseraga (Dansville) valley, about three miles away. This divide is at nearly the same altitude as the village, or about 900 feet, and gave free connection with the Dansville lake at the higher levels of the latter.

*DELTAS AND WATER-LEVELS.*

There are two conspicuous levels in the Scottsburg valley. The higher one is at about 1,250 feet and corresponds to the Dansville summit levels. The finest example seen of this level is at the village of Conesus on the Erie railroad, three miles east of the head of the lake, where the Conesus creek debouched into the expanded waters held up to the level of the Dansville lake. The lower level is seen at many points along the valley sides where streams have built deltas at a height estimated at 80 to 100 feet above the lake, which has an altitude of 819 feet. The village of Scottsburg is located on the delta of Inlet creek. The large lower delta of Conesus creek is, in its highest part, apparently something over 100 feet above the present lake.

*LAKE HISTORY.*

The valley of Conesus extends so far north of the parallel of Mount Morris that the north end was probably closed by the ice after the Dansville lake had been lowered into the vast Warren water which then buried all the ice-uncovered area of western New York and the Great lakes. In this event it would have overflowed by the gap at Scottsburg, but the fall could not have been many feet, and it is possible that this col was near the level of the Warren lake. Further observation is required to determine the full history of the Scottsburg water.

## The Naples Lake.

*CANANDAIGUA VALLEY.*

The present lake is about 15 miles long. The village of Naples lies about 4 miles south of the head of the lake, and it is 4 miles more to the col. The valley is from one to two miles wide, but at Naples is narrowed to only about half a mile. The moraine is remarkably developed and occupies 4 miles of the head of the valley, from near Naples

to near Atlanta. The elevation of the lake is 687 feet. Naples lies about 100 feet higher. The walls of the valley here rise directly 800 or 900 feet, and the surrounding tableland is more than 2,000 feet above tide.

### *DRAINAGE.*

A number of streams pour into the valley near Naples. From the northwest comes West Hollow creek. This is joined from the west, not far from the village, by Springstead brook. From the southwest comes Naples brook with several tributary brooks, the main one being the Garlinghouse, from the west. From the south comes Olney brook; from the southeast Tannery Glen brook. All these minor streams united make Naples creek, which, near its mouth, three and a half miles north of the village, is joined by West river, the latter heading near Rushville, between Canandaigua and Seneca lakes, and flowing southwest.

### *DIVIDE AND CHANNEL.*

These streams all occupy deep valleys cut out of the tableland, and head near streams flowing into other drainage systems. The lowest of them all is West river; but this, coming from the northeast, was under the ice while the southern divides were uncovered. The next lowest divide is the col to the west, between the Springstead brook and the inlet of Honeoye lake, but the northern outlet by Honeoye lake was also in the earlier life of the lake dammed by ice. The lowest southward outlet was over the col between Naples brook and the Cohocton creek, near Atlanta (formerly Bloods), on the Erie and the Delaware, Lackawanna and Western railroads. This divide has an altitude of about 1,340 feet.

The outlet channel of the Naples lake is a good example of an abandoned river-bed. It is something over a mile long, 20 to 25 rods wide, with banks 15 to 20 feet high and a flood-plain of varying width. It heads at the divide among hills of drift, and pursuing a nearly straight course it opens into the Cohocton valley about one mile northwest of Atlanta station. The highway leading northwest from Atlanta into the Naples valley crosses the channel by the house of William Rowe, at which point the direction of the channel changes from south to west of south (see figure 1, plate 19).

No stream of consequence has occupied this channel since it was abandoned by the overflow of the glacial lake, and the pavement of cobbles and bowlders in the bottom of the channel is still well shown through the vegetal accumulation.

### *DELTAS AND WATER LEVELS.*

Fine deltas have been produced by all the side streams entering the valley and debouching into the deep lake. They are fairly well preserved and the terraces are conspicuous (see figure 2, plate 19).

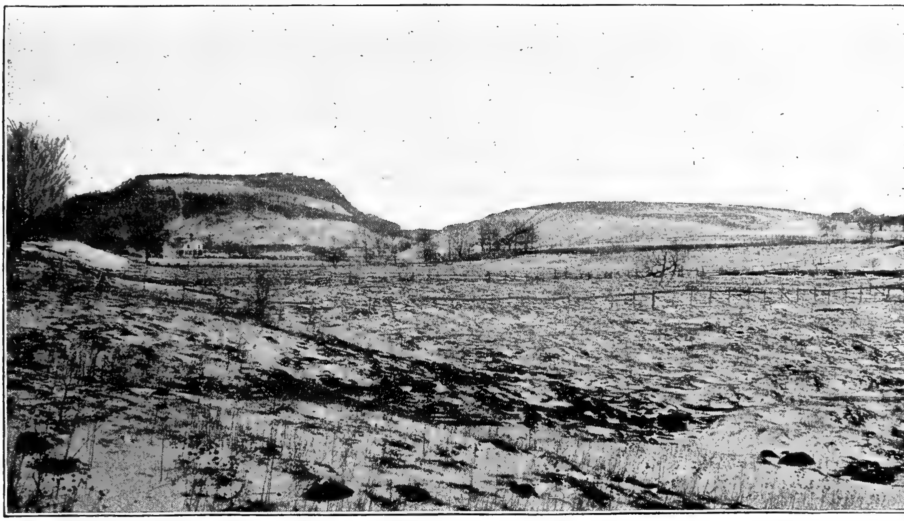

FIGURE 1.—OUTLET CHANNEL.

View looking north, or upstream, from near the mouth of channel.

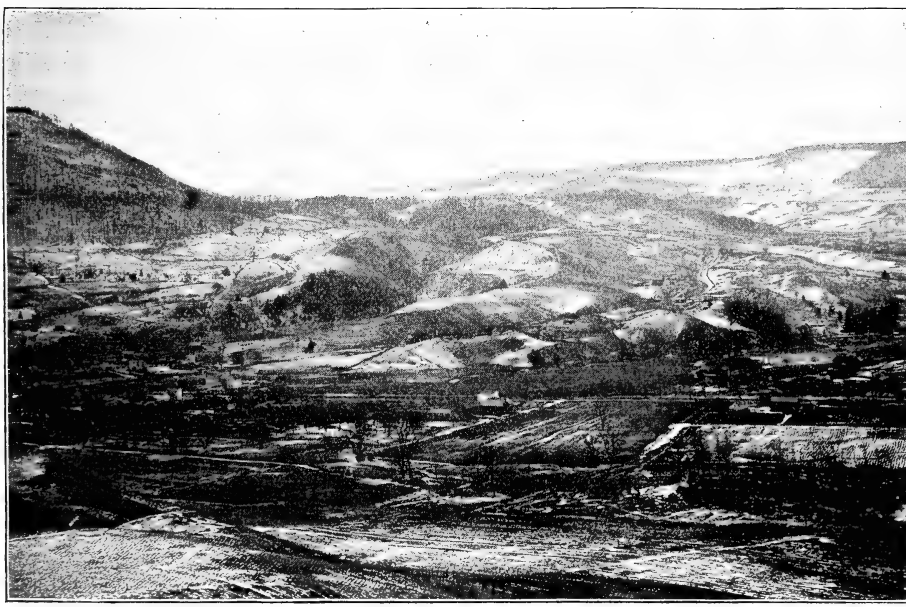

FIGURE 2.—TANNERY GLEN DELTA.

View is taken from the Braun's Hill terrace of the Springstead delta; looking southeast.

NAPLES LAKE.

1. The highest level, the Garlinghouse, is the height of the lake outlet. The lowering of the outlet by the stream-cutting and the erosion of the plateaus has given an indefinite surface to these terraces, which are not yet measured, but they are surely above the col. This level shows at the top of all the deltas as the broad plateau. It makes the plain at the head of the Garlinghouse delta, three miles southwest of the village, the plain above the Tannery Glen delta southeast, and shows as erosion terraces and benches in various parts of the valley.

2. The Crippen level is the top of the delta made by the Springstead brook and West Hollow creek, immediately over the village on the west. Corresponding levels are found on the Tannery Glen delta. The altitude is 1,192 feet.

3. The main Springstead level is 1,127 feet. This is the broader expanse of the Springstead delta, a pronounced plateau above the village. It was produced by the overflow of the ice-dammed waters of Honeoye lake.

4. Oak Hill level, 1,114 feet, is a lower terrace of the Springstead delta.

5. Brauns Hill level, 1,088 feet, is another still lower terrace of the Springstead delta. A corresponding terrace is Tylers orchard, south of the village one and one-half miles.

6. Cemetery level is a well developed terrace of the Springstead-West Hollow creeks delta, but consists of two or three minor benches. Two altitudes taken were 1,011 and 1,002 feet.

7. Bobnick level, 909 feet, is named after the local appellation of the lowest of the terraces. Corresponding levels are seen on the east side of the valley at Hinkley's vineyard, on Hatch hill, and also at the top of Parrish Gully delta, two miles northeast of the village.

### *LAKE HISTORY.*

The history of this lake is complicated, and is involved with that of the glacial Honeoye lake. At its maximum the glacial lake was more than 600 feet above the present lake, which has a depth of over 200 feet. Its waters were then united with those of the ice-dammed Honeoye and reached far up the branching valleys. The outlet was over the southwest col to the Cohocton creek. At this stage were built the upper terraces of the Garlinghouse delta, of the Tannery Glen delta, and of the West Hollow creek delta and other plateaus. From this level the lake did not fall suddenly, but by a series of depressions, as the ice-removal uncovered the land between this lake and the glacial Seneca lake. This plateau is of only moderate height and slopes northward. The Northern Central (Pennsylvania) railroad crosses it diagonally from Watkins to Canandaigua, and the summit of the road near Stanley is 911 feet. The West

river or Middlesex valley gave a northeast channel toward Stanley. As the waning ice-sheet thinned and weakened over this divide, masses of the front were probably lifted and removed by the buoyant water, and lower outlets along the ice-front were thus opened rather suddenly. This probably accounts for the several unusually distinct terraces upon the deltas.

It is possible that for a time the waters flowed northwest through Honeoye valley, if the ice-blockade was removed there earlier than over some particular level south of Stanley, but the col between the Canandaigua and Honeoye valleys has not at this writing been examined, and that question will be considered in a future description of the Honeoye glacial lake.

The lowest terrace is thought to represent the level of the great water which united all these local lakes until the Mohawk outlet was opened.

## The Hammondsport Lake.

### *KEUKA VALLEY.*

The glacial lake which formerly filled this valley to southward overflowing had on account of the simple character of the geography a comparatively plain history. The lake is eighteen miles long, one mile wide, and is forked at the north end. Its depth at the southern end averages about 160 feet. The walls rise abruptly for about 500 feet, and more gently to a height of 1,000 to 1,200 feet above the present water surface. Through these high walls of the plateau there are no breaks, except at the two ends of the valley. The lake level is preserved for two or three miles in low, swampy land, characteristic of the heads of the linear lakes, to the point where moraine-kame filling begins, which extends four miles further. The south end of the valley is chiefly drained by Inlet creek, about six miles long, with its many tributary brooks. At the head of the lake two smaller streams have cut ravines, one on either side of the valley, the Laughlins Glen brook coming from the east and joining the inlet near its mouth, and the Glen brook from the west flowing through the village of Hammondsport, which lies against the southwest corner of the lake, and debouching directly into the lake.

### *DIVIDE.*

The glacial outlet was over the moraine and kame filling of the south end of the valley, which begins about three miles from the lake and continues four miles to near Bath, where it becomes an overwash gravel-plain. The general height of the divide is about 1,150 feet above tide.

The stream channel, which is fairly distinct, has an altitude, using the Bath and Hammondsport railroad levels as data, of about 1,125 feet.

### *DELTAS AND WATER-LEVELS.*

The levels are marked clearly in the terraces of the two stream deltas at the head of the lake and in others along the sides of the lake. On the conspicuous deltas at Hammondsport only two terraces are seen. Taking Keuka lake as 718 feet, the broad plateaus of the deltas are 1,158 feet above sealevel, and the lower terrace, seen as a conspicuous but not large shelf on the Laughlins Glen delta, is 911 feet.

On the west side of the lake, one and a half miles from Hammondsport, is a high delta at the mouth of Snows glen; at two and a half miles is another at the mouth of Adsit Baileys gully (Malvareau point), and a fine delta exists at Urbana. Others are said to occur at several stream outlets farther down the lake. These deltas have not been measured, but a careful estimate of the broad lower terrace of the Urbana delta was made, with the conclusion that it was not far from 200 feet above the water.

Evidences of lake-action are not seen upon the steep slopes near the head of the lake. The friable character of the shales is unfavorable to the preservation of shorelines. The slopes are ravined at frequent intervals, and the vineyards which make the locality famous are seamed with many small gullies of recent origin.

### *LAKE HISTORY.*

It is a simple story. While the ice-lobe was retreating the whole length of the valley the water was held up to the top of the moraine divide, 440 feet above the present water-level. Toward the close of this stage the lake was 24 miles long, 2 miles wide and 600 feet deep. When the low ground at the north end of the valley was uncovered, the glacial lake fell to the level of the Watkins (Seneca glacial) lake, which had an altitude something over 900 feet.

## The Watkins Lake.

### *SENECA VALLEY.*

This valley is of simple character, a single north-and-south depression, with no branches or side cuts, and in general proportions it resembles the Cayuga valley. The present Seneca lake is 38 miles long, from one to three miles wide, and the southern half averages 500 feet deep. At the south end of the lake and at the head of the valley the land on either side rises steeply from the water for 500 feet, and then in more gentle

ascent to a total height of 1,500 or 1,800 feet above tide. The narrow valley retains nearly the lake level for 3 miles south from the head of the lake, or to Havana, where begin the morainic and gravel hills which continue with increasing altitude for 8 miles to Pine Valley. From here the valley widens out into a plain with but little change of level for 5 miles, to Horseheads, and with a fall of only 40 feet in the next 6 miles to the flood-level of the Chemung river at Elmira.

From the south Catherine creek drains the moraine-filled valley from near Horseheads and reaches the lake at Watkins. Only small streams flow down the steep slopes of the valley, often with postglacial rock-cutting. The two most notable streams and ravines near the head of the lake are at Watkins and Havana.

*DIVIDE AND CHANNEL.*

The character of the col and its relation to the valleys southward deserve fuller description than can now be given. Through the courtesy

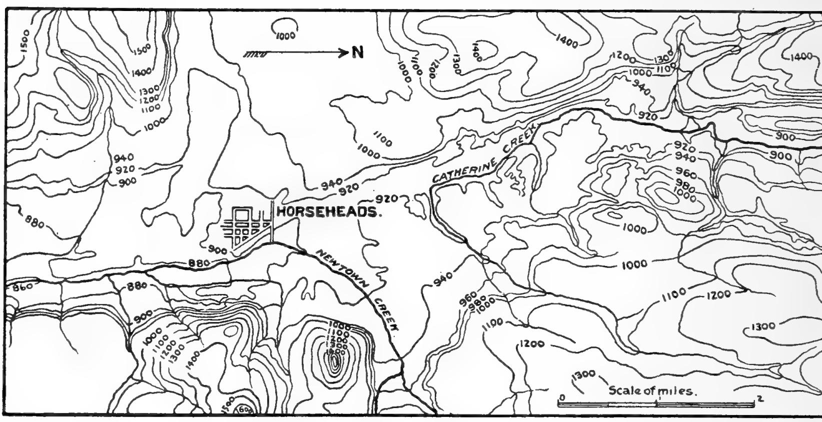


Figure 1.—*Outlet of the Watkins Lake.*

of the United States Geological Survey the personal study of the locality has been supplemented by the manuscript of the unpublished Elmira sheet of the New York topographic map, a portion of which has furnished the basis of the accompanying sketch.

The parting of the waters is close to the village of Horseheads, where Newtown creek, draining the eastern highlands, flows south past the village to Chemung river, and Catherine creek heads and flows north to Seneca lake. The true glacial channel, with definite banks and flood-plains, begins at the water-parting three-fourths of a mile north of the village of Horseheads (see figure 1, plate 20). At this point it is about

FIGURE 1.—HEAD OF OUTLET CHANNEL.

View is from lower flood-plain, west side, looking east of south; Horseheads village in middle distance; upper flood-plain shows at right.

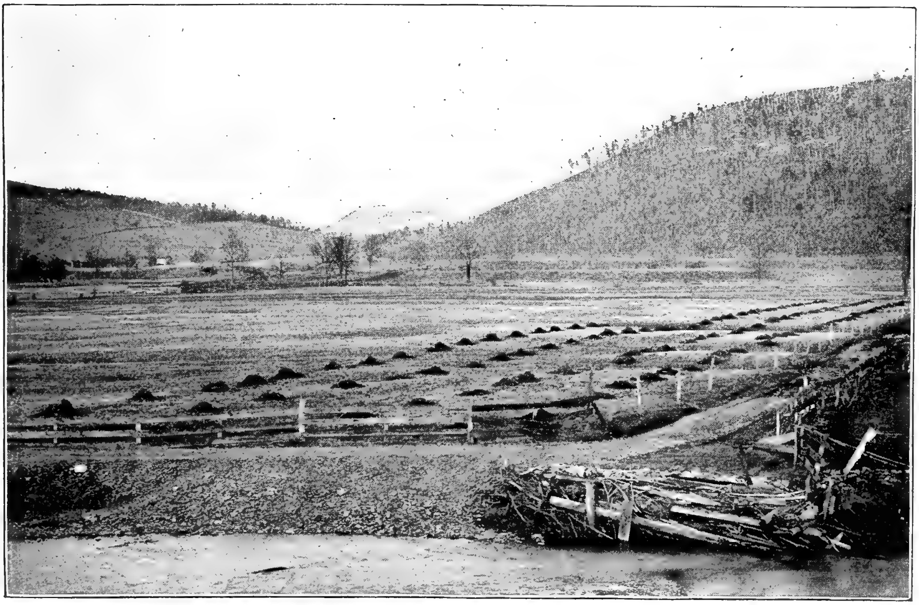

FIGURE 2.—CHANNEL AT HORSEHEADS.

View from lower flood-plain, south of the village, looking north of east, across the narrower deep channel. The two terraces are clearly seen on the opposite side. Newtown creek in foreground.

WATKINS LAKE.

one-fourth of a mile wide, with bluffs and two narrow flood-plains 20 and 40 feet in height. For the 7 miles to Chemung river the channel has a nearly straight course, with a direction east of south. At its head the channel lies near the west rock-wall of the great preglacial valley; from Horseheads to Elmira its deepest section lies close to the east wall. The sketch (figure 1) does not fairly indicate the channel.

At the north edge of the village of Horseheads the lower flood-plain is strongly developed. The village lies upon this broad gravel plain, 20 feet higher than the deeper eastern channel. The electric railroad between Elmira and Horseheads runs along the eastern edge of the 20-foot plain, and gives good views of the deep section of the channel, which is now occupied by Newtown creek. The upper gravel flood-plain, 20 feet above the lower plain, or 40 feet above the channel bottom, forms a bluff in the western edge of Horseheads village, upon which the cemetery is located, and spreads westward through another broad preglacial valley toward the Chemung river at Big Flats. The two terraces show clearly also upon the eastern side of the valley (see figure 2, plate 20).

From Horseheads down the valley the eastern deep section of the channel is about one-third of a mile in breadth. The 20-foot flood-plain is half a mile wide, making the width between the 40-foot bluffs nearly one mile.

The channel, with its bordering gravel plateaus, has a southward decline of 40 feet between Horseheads and Elmira, or a slope of about 7 feet per mile.

Upon the divide, and for some distance in either direction, the channel bottom is covered with peat and the depth to rock is unknown. At Horseheads, rock is not found at the depth of 200 feet.

The northward descent from the water-parting is gentle as far as Pine Valley, where the deep glacial lake-basin commences. The Northern Central railroad follows the old stream channel, and the profile of the road makes the altitude of its tracks at Pine Valley 895.3 feet, and at Horseheads 902 feet. At the latter point the railroad is upon the first or lower flood-plain. The abandoned Chemung canal also traversed this channel, and the altitude given for the "level" between Pine Valley and Horseheads is 884 feet, being probably the bottom of the prism.

From one mile north of the divide to Pine Valley the channel is narrower and shows no terraces, and seems somewhat out of harmony and proportion with the capacious channel and heavy gravel plains at Horseheads. Upon the east side it is bounded by low hills, consisting of till, so far as positively known. The west wall, which forms the outer side of the curve, is rock. At a point midway between the water-parting and Pine Valley the bottom of the channel is also rock, which was recently

blasted for some distance in deepening the old canal for better drainage (see figure 1, plate 21).

In being narrowed and interrupted by morainic drift north of the water-parting this large channel agrees with the smaller outlet channel of the Naples lake, but does not agree with the channel of the Ithaca lake.

It is suggested that the relative altitudes of north and south portions of this valley may now be somewhat changed from what they were during the existence of the glacial lake. Northward differential uplift may have raised Pine Valley somewhat; in other words, it is possible that Pine Valley may have been relatively lower during the life of the Watkins lake, and the drift-hills have been partially submerged, the current of water starting from a point so far below as not to seriously erode them.

### *DELTAS AND WATER-LEVELS.*

On the west side of the valley, at Havana, is a delta conspicuous from the village. Across the valley is the famous Havana glen, with a broad delta showing on the higher ground, but not measured. The finest delta is at Watkins, where Glen creek has cut the remarkable ravine after bisecting its delta. The village cemetery occupies the slope of this deposit of gravel, which has several terraces. The summit is a flat gravel plain more than a mile wide, with a measured height above the lake of 521 feet. Adding the lake height, 440 feet, gives the summit an altitude of 961 feet, which is 61 feet above the channel of the Horseheads divide, and 20 to 30 feet over the broad flood-plains bordering the channel. A small terrace occurs at 917 feet; a strong terrace at 883; another broad plateau, which is the upper field of the cemetery, at 790. These were all measured upon the north side of the ravine. Apparently another terrace occurs at 760 feet upon the south side of the glen (see figure 2, plate 21).

During another season of field-work careful measurements will be made of other deltas and the levels compared. Doubtless many stream deltas along the lake will show summit plateaus at a plane corresponding with the expanded summit of the Watkins delta, but the full correlation of the lower terraces cannot be so confidently expected.

### *LAKE HISTORY.*

*Coalescent Waters called Lake Newberry.*—While the water rested at the highest level, something below the summit plateau of the Watkins delta, it had a general depth over the Havana plain of 500 feet, and over the site of the present lake of 1,000 feet. The local lake must have attained a length of thirty to forty miles, with a breadth of perhaps five miles,

FIGURE 1.—PASS NORTH OF THE DIVIDE.

View is looking southward, up Catherine creek, from a point one mile south of Pine Valley station. The water-parting is two miles away and invisible in the hazy distance. Rock walls upon the right, hills of drift (?) upon the left.

FIGURE 2.—WATKINS GLEN DELTA.

The point of view is the middle of the plain, by the bank of the abandoned Chemung canal; looking west over Watkins village.

WATKINS LAKE.

before the water could escape over the plateaus either side of the north end of the lake at a level under 900 feet.

After the lake had attained by the northward recession of the ice-dam a length of about twenty to twenty-five miles from Pine valley, it received the overflow of the Hammondsport lake, and soon afterward it probably received the waters of the Naples lake. If the receding ice-front held an east-and-west trend across the region of these lakes, there must have been a stage when the waters of the Watkins lake coalesced with the waters filling the Canandaigua and Keuka valleys upon the west, and the Ithaca and perhaps other valleys on the east, up to the 900-foot level.

To this more widely expanded water at the Horseheads level, uniting probably several of the local lakes, it seems desirable to give a non-geographic name, and the author proposes a name honored in American geology and prominently identified with the glaciology of the Laurentian lakes. Let it be known as lake Newberry.

*Possible Relation to Warren Waters.*—The Horseheads channel is at present the lowest and best developed of all the passes over the divide east of lake Erie. At the time we are considering it was probably, by the depression of central New York, the lowest outlet east of Chicago. Consequently, if the vast Warren waters, into which all these local glacial lakes were drained or with which they were blended, found, by the depression of the region, any southward escape lower than Chicago while yet the Mohawk valley was ice-covered, then the Horseheads pass was such outlet. In this case lake Newberry retained its level as a part of the great lake succeeding lake Warren.

## The Ithaca Lake.

### *CAYUGA VALLEY.*

The geography of this valley and its glacial history is similar in general to that of the Dansville valley and lake. Its proportions are on a larger scale, but there is the bifurcation southward and the double lakes in the beginning blending later into one. The lower outlet in the Ithaca lake is, however, the eastern one.*

Cayuga lake has a length of 38 miles and a breadth of one and a half to three miles. Its altitude is 378 feet above tide; its depth more than 400 feet. The main valley reaches about two miles farther south, to South hill, in Ithaca, where it divides. The main branch, or Cayuga

*The topography, drainage and altitudes are well described in "The Cayuga Flora," by Professor W. R. Dudley, to whom the writer is indebted for many facts in the description of this basin. Some of the figures of altitudes are changed to agree with later determinations.

Inlet valley, continues southward, with the divide 12 miles from Ithaca, at Spencer Summit, and leading over the col to the Susquehanna at Waverly. The lesser branch is directed southeast, forming the valley of Six Mile creek, with the divide ten miles from Ithaca, and leading over to the Susquehanna at Owego.

There are several streams debouching into the head of the main valley (see figure 2, page 372). Cayuga Inlet creek has several tributaries from the south, Buttermilk creek and Coy Glen brook joining within two miles from Ithaca, Butternut (Enfield) creek two miles farther up the valley, and the West Branch (Newfield) creek and Lick brook six miles from Ithaca. Six Mile creek, draining the southeast valley, joins Inlet creek in the city, two miles from the lake. Two important streams come in from the east—Fall creek at the north of Cornell University grounds, and Cascadilla through the University grounds and the city. Both of these creeks have cut deep postglacial ravines. Many smaller streams have cut similar ravines all along the lake-shores. Taughannock and Trumansburgh creeks on the west and Ludlowville creek on the east are the most important.

### *DIVIDES AND CHANNELS.*

The moraine in the Cayuga Inlet valley extends from Newfield station, on the Lehigh Valley railroad, south to Spencer Summit, a distance of 8 miles. The abrupt upper or south end of the moraine forms the col. From this point southward is an open valley. The railroad finds a low pass near the west wall of the valley, with a summit elevation of 1,065 feet, one-fourth of a mile north of Spencer Summit station. The old stream channel, which once carried the overflow of the glacial waters from the lake north of the divide, is, however, upon the extreme eastern side of the valley, upon the farm of Mr A. Signor. The head of the outlet is at the north border of the only primitive pine forest in the Cayuga basin, at which point the morainic hills fall off steeply to the deep valley northward. The channel runs southeast through the pine forest about 80 rods, then some 40 rods through cleared fields (see figure 1, plate 22), and then bends abruptly to the east, and in 20 rods reaches the Cattatonk creek (see figure 2, plate 22), which enters the valley from the north and at this point flows in a rock bed at the very base of the eastern rock-wall of the valley. Just before reaching Cattatonk creek the channel crosses the highway close to the house of Mr S. D. Turk. At this point it is about 12 feet lower than at its head in the north edge of the forest. This figure is upon the authority of Mr Signor, who relates that during a flood of the creek in June, 1855, the waters set back up the extinct channel until some water actually fell northward toward Cayuga lake, the flood standing 12 feet high on the buildings by the highway. The

FIGURE 1.—MIDDLE PORTION OF CHANNEL.

View looking south, and downstream, from edge of pine forest. In the left background the channel turns abruptly to the left.

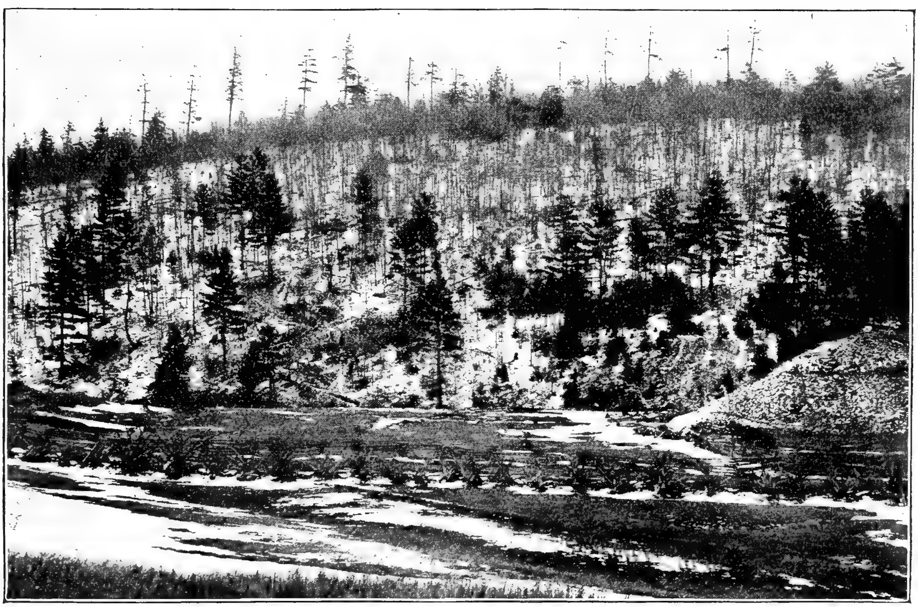

FIGURE 2.—MOUTH OF CHANNEL.

View looking east, showing sudden termination of channel in Cattatonk creek, which flows at the base of the rock wall. Point of ridge at the right is rock.

OUTLET CHANNEL OF WEST DANBY LAKE.

channel is 10 to 15 rods wide, and is the smallest and shortest of the ancient lake outlets so far seen by the writer.*

The altitude of this outlet is not accurately determined, but is estimated, by comparison with the railroad across the valley, at about 1,040 feet.

Southeast of Ithaca, in the valley of Six Mile creek, the moraine is not so well developed as in Inlet valley, and has suffered much erosion. It ends north of the divide, the heavy deposit reaching only to Caroline, and the col being a mile further south in a long stretch of open valley.

The divide is at the Bell schoolhouse, one mile south of Caroline station, where the valley is nearly one mile wide between the rock walls, and the swampy bottom is one-fourth of a mile wide. Including the divide, and for considerable distance north and south, the valley bottom is nearly level. The altitude of the Delaware, Lackawanna and Western railroad at the crossing of the divide is 985 feet, which is perhaps 10 feet above the low ground. The Beaver and Wilseyville creeks emerge from ravines in the western rock-wall of the valley, and after nearly meeting, part company, the former flowing north to join Six Mile creek, the latter south to join the Cattatonk below Wilseyville.

The head of the definite stream channel is about a mile below the divide, at White Church station, with a width of about one-eighth of a mile and with walls perhaps 20 feet high. The tracks of the Delaware, Lackawanna and Western and the Elmira, Cortland and Northern railroads lie in the channel from White Church to below Wilseyville. At Wilseyville the valley widens, and the channel is bordered by extensive flood-plains (see figure 1, plate 23).

### *DELTAS AND WATER-LEVELS.*

*Location and Height.*—The deltas are not large compared with those of the other glacial lakes and with the size of the valley, both branches of which were lake outlets for a time—the detritus being borne south to the Susquehanna basin. When the fall of the lakes reversed the drainage, the inpouring streams from the cols spread their load over the many miles through which the moraine stretches; but the side streams have built definite deltas. The most conspicuous near Ithaca are on the steep slopes at Coy Glen (see figure 2, plate 23), Buttermilk, Enfield, and Newfield ravines. The deposits of Fall and Cascadilla creeks are spread out on the plateau above the campus of Cornell University. Other deltas are seen at the mouths of streams down the valley or northward.

In the valley of Six Mile creek are conspicuous terraces of considerable extent. There are two of these levels. The upper is above the White

*The author is indebted to Mr G. K. Gilbert for indicating the location of this channel.

Church divide about 35 feet, as determined by hand level, or at an altitude of 1,020 feet. The same terrace farther north, as measured by the engineering department of Cornell University, is from 1,014 to 1,028 feet. The lower terrace has not been measured.

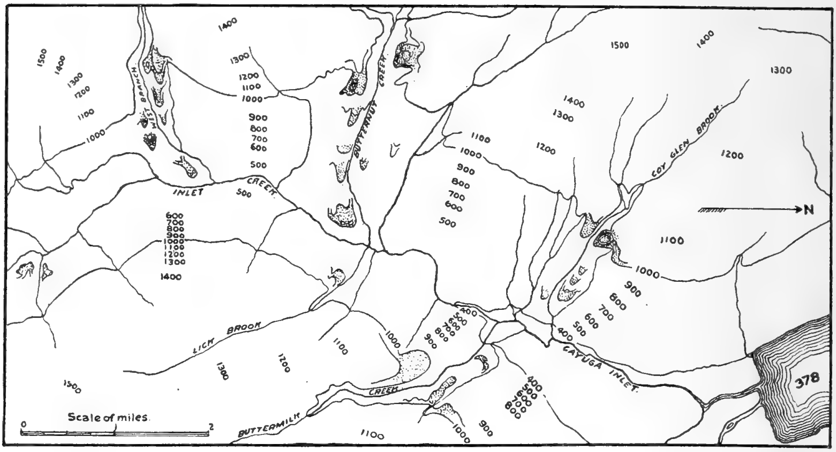


FIGURE 2.—*Delta Terraces in Cayuga Inlet Valley.*

*Comparison of Terrace Levels.*—In the Inlet valley the deltas of all the streams show conspicuous but not large terraces. For their illustration the writer is permitted by the courtesy of the United States Geological Survey to use the unpublished Ithaca sheet which covers the Inlet valley,

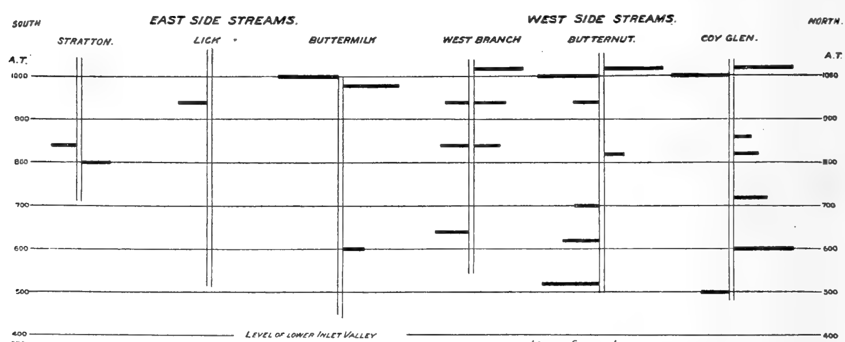


FIGURE 3.—*Approximate Height of Terraces in Cayuga Inlet Valley.*

but not the Six Mile creek valley. Upon each of the four principal deltas, namely, Coy Glen, Butternut, and West Branch upon the west slope and Buttermilk on the east slope, the best developed terrace is shown in every case at the delta-summit, and is bounded at the lower edge, with

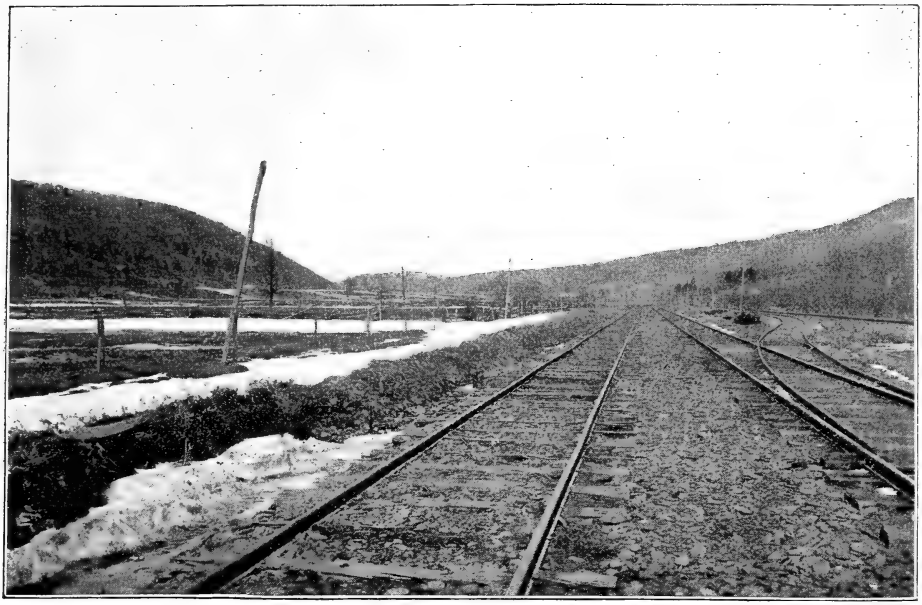

FIGURE 1.—OUTLET CHANNEL AT WILSEYVILLE.

View from Wilseyville station, looking north. At this point the channel widens. Heavy flood-plain is seen in distance, on west bank.

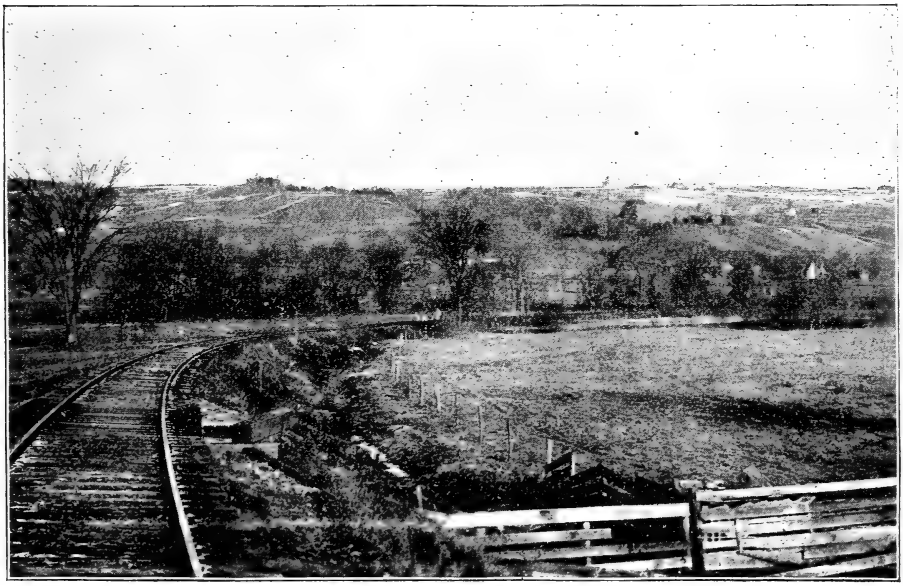

FIGURE 2.—COY GLEN DELTA.

View from middle of Inlet valley; looking northwest.

ITHACA LAKE.

only one exception, by either the 1,000 or 1,020-foot contour. The sloping surface of the terraces could not be below these levels, but might be a few feet higher. It will be observed that this height agrees closely with the higher terrace in the valley of Six Mile creek, and evidently indicates the water-level of the Ithaca lake while overflowing by the White Church outlet.

The manuscript map does not definitely show by the contours any terraces marking the higher level of the earlier water, which must have been restricted to this western valley with the overflow by the col at Spencer Summit. Such evidences of water surface should be sought at an elevation of about 1,060 or 1,070 feet.

Several small terraces lower than those above described are, however, found on these deltas. Three deltas show terraces at 940 feet, four at 820 to 840, two at 700 to 720, and four at 600 to 640. Two deltas also show small terraces at 500 to 520 feet, only about 100 feet above the valley bottom, and 122 feet above Cayuga lake.

In the sketch the terraces are indicated by the dotted areas, and the height of the contour-line bounding the lower edge of each area is given in the comparative table. In the latter an attempt is made to represent graphically the relations of the several terraces. The vertical lines indicate the ravines which bisect each delta deposit. As the sketch is taken from the Geological Survey map, the contours are 20 feet apart, and on that account may not fully represent the correspondence in height of the terraces. Closer contouring would not lower the higher terraces of any set, but might raise the lower ones so as to produce a much nearer approximation to one level.

*Variation in Height of Terraces.*—It is evident that the subsiding waters were able to produce minor terraces upon the steep slopes of the incoherent stream deposits during relatively brief halts, but the interaction of lake and stream, with varying conditions of wind, slope of shores, and amount and character of material, caused the delta terraces to vary considerably in height within short distances or even in the two sides of the same terrace. However, notwithstanding the variation in height, the sketch and table show a substantial relationship between the terraces of all the streams in the Cayuga Inlet valley.

### *LAKE HISTORY.*

*West Danby Lake.*—In the early stages of the ice-retreat there was a minor lake in each of the two southern forks of the valley, these separate lakes being held up to the height of their respective divides, and this condition continued until the ice-retreat had uncovered the point of South hill. The lake in the Inlet valley requires a separate name, and may be

called the West Danby lake. When the ice-front had passed the north point of South hill, in the city of Ithaca, the West Danby lake fell only about 50 feet to the level of the lower lake in the southeast valley, and then began the major stage of the Ithaca lake.

*The main Lake.*—This level must have been preserved during the considerable time which was required for the front of the glacier to retreat more than half way down the Cayuga valley, or until the crest of the tableland east or west of the valley was uncovered at an altitude less than the White Church outlet. The waters then probably fell about 85 feet to the level of the Watkins lake, thus forming a part of lake Newberry, and subsequently to any lower levels of the great lake which covered all of northwestern New York until the ice was removed from the Mohawk valley.

The Ithaca lake was the largest and deepest of the local glacial lakes of western New York. At its maximum it was probably 35 miles long and perhaps from 5 to 10 miles wide. Its depth was more than 600 feet over the present level of Cayuga, and at the north end the total maximum depth was over 1,100 feet. This would seem to be sufficient proof of the competency of glacial ice to act as a barrier retaining a great depth of water.

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# CRETACEOUS OF WESTERN TEXAS AND COAHUILA, MEXICO

BY E. T. DUMBLE

(*Presented before the Society December 29, 1894*)

CONTENTS

## Introduction.

While in its broader features the Cretaceous of western Texas and of the northern portion of the Mexican state of Coahuila corresponds closely with that of the Colorado River section east of it, there are, nevertheless, many important differences in the stratigraphy and faunal relations well worth more detailed study than they have yet received. A few of these differences, which have come under my personal observation during trips made through various parts of the region, are presented as indicating the general character of the formation.

## Localities of Occurrence, Character and Relations of the Rock.

Only a few remnants of areas are found north of the Texas and Pacific railroad, and that line may well be taken as marking the northern boundary of the Cretaceous deposits of western Texas, since, as a body, they pass north of it only (if at all) under that portion of the road which crosses the Llano Estacado.

In Trans-Pecos Texas the basal rocks of this Cretaceous system are best exposed in the vicinity of the railroad, and, as the Rio Grande river is neared in going south from it, beds higher and higher in the section are found. The country, as a whole, slopes rapidly from the north toward the river, and, while in the southern portion of the area the Cretaceous rocks are found at some of the highest altitudes, along the railroad they occur as the foot-hills of the mountain-blocks, whose cliffs of Silurian and Carboniferous limestones tower from 1,000 to 2,000 feet above them, or as detached mesas, buttes or ridges in the wide spread flats which separate these mountains.

Much of the limestone of the Lower Cretaceous is metamorphosed as highly as is that of the Carboniferous, and is consequently as well adapted to withstand erosion, yet no trace of it has been observed upon the tops of the ranges north of the railway. Even where it now occupies higher altitudes in this region, as on Sierra Blanca and in the vicinity of Gomez peak, in the northern portion of the Davis or Apache mountains, its position is evidently due to the orographic action which formed the mountains.

So far as I have observed, while the Carboniferous rests indiscriminately on various horizons of Algonkian and Cambrian, the Cretaceous has only been found in contact with the Carboniferous, Permian and Triassic.

## San Lorenzo Section.

### *Its Location and the Character of the Country.*

This section was made in northern Coahuila, beginning at the head of the San Diego river, in that portion of the Burras range known as the

Arboles mountains, and extending eastward and northward to the confluence of El Soro creek and the Rio Grande river, a distance of nearly 60 miles. The uplift which formed the Arboles mountains brought up the basal divisions of the Lower Cretaceous series and gave them a strong tilt to the east and northeast, thus forming a synclinal of Cretaceous rocks in the area between the mountains and the highlands north of Del Rio. Near the river the country is somewhat hilly; but between these hills and the mountains lies an undulating plain, the highest point of which is formed by the crest of a gentle fold of Washita limestone. On reaching the San Diego river the country becomes rugged and mountainous, rising rapidly, and the peak near what is known as the Saddle is 3,700 feet above sealevel, while the plain is only about 1,500 feet.

### *DETAILS OF THE SECTION.*

The highest beds, geologically, are found on El Soro creek, and it is at this locality only that beds of the Upper Cretaceous (or Black Prairie series of Hill) are found, and even here they have a very limited extent. The entire area may be said to be Lower Cretaceous.

The general section is as follows:

| | Feet. |
|---|---|
| *Post-Cretaceous.* | |
| Stream gravel and brown silt covering part of flat between Las Vacas and the San Diego river. Reynosa conglomerate. On hilltops and along the San Diego ........ | |
| *Upper Cretaceous.* | |
| Eagle Ford stage.—Limy clay, shales and flags. Soro creek ........ | 40 |
| *Lower Cretaceous.* | |
| Vola stage.—Heavy bedded semicrystalline limestone of creamy white color. *Vola roemeri*, Hill. El Soro creek ........ | 80 |
| Exogyra arietina stage. Blue, yellow and red clays, with bands of sandy flagstones and concretionary limestones. *Exogyra arietina*, Roem.; *E. drakei*,* Crag.; *Nodosaria texana*, Con.; *Pecten*, sp. undet. Hills near Rio Grande ........ | 110–140 |
| Washita Limestone stage.—Marly limestone, white to blue in color, semicrystalline in places, arenaceous and bituminous at base. *Ostrea carinata*, Lam. Surface rock of the plain ........ | 300–400 |
| Caprina stage.—Dark blue or gray semicrystalline limestone, massive or heavy bedded, with much flint. *Caprina crassifibra*, Roem.; *Gryphæa* and sponges. Along the San Diego river and in Arboles mountains ... | 600– (?) |

* Professor Cragin says of the specimens of *E. drakei* which I submitted to him: "The tendency to freer beak than is usually seen in north Texas specimens makes it bear a degree of resemblance to *E. arietina*, with which, however, it could not be confounded."

| | Feet. |
|---|---|
| Comanche Peak and Exogyra texana stages.—Thin bedded, marly lime- Mort.; yellow to blue in color. *Exogyra texana*, Roem.; *Gryphæa pitcheri*, stones, *Ostrea crenulimargo*, Roem., etcetera. Arboles mountains....... | 120–150 |
| Glen Rose stage.—Thin bedded, marly limestones underlaid by heavy bedded limestone, with interbedded marly shale. *Requienia texana*, Roem.; *Pleurocera strombiformis*, Schlot. (*Vicarya branneri*, Hill); *Natica*, *Exogyra* and *Gryphæa* of undetermined species. Arboles mountains. Base not seen.......................................... | 300– (?) |

This is the only Mexican area which I have had an opportunity of examining. Other details of the section will be given below in connection with those of various Texan localities.

## Lower Cretaceous.

### *BOSQUE DIVISION.*

*Its Members.*—The Trinity sands, Glen Rose or Alternating beds and Paluxy sand, which constitute the three members of the Bosque division at the typical locality,* have only been found together in west Texas, in the vicinity of Sierra Blanca Junction. At all other localities one or two of these members are missing.

*Flat Mesa Section.*—The section of Flat mesa, beginning one mile north of the Junction, gives:

| | Feet. |
|---|---|
| Paluxy stage.—Brown quartzitic sandstone.................................... | 35 |
| Silicious conglomerate and grit.... ........................... | 10 |
| Brown sandstone ............ ............................. | 46 |
| Alternating stage.—Arenaceous limestone, with *Actæonella dolium*, Roemer, and a small *Exogyra*.................. ....................... | 4 |
| Trinity stage.—Brown quartzitic sandstone, exposed........................ | 100 |

This section is repeated in the hills just south of the Junction, with interstratal sheets of rhyolite and extrusions of porphyry.

*Kent Section.*—In the section made at Kent (which corresponds in this respect with the sections made at the southeast point of the Llano Estacado and at Double mountain) we found no trace of the Alternating beds and only one stratum of sand, which is therefore referred to the Paluxy, because, as Taff has shown, at no place has the Fredericksburg been found resting directly on the Trinity. This sand, at Kent, rests unconformably on a semicrystalline limestone, presumably of Permian age. It contains the largest amount of silicified and opalized wood which I have found in Texas, and it may be that a study of this would decide whether the sand is altogether Paluxy or whether it includes both Paluxy and Trinity.

* Taff: Third Ann. Rep. Geol. Survey of Texas, p. 301.

*Exposures in the Arboles and Burras Mountains.*—In the Arboles and Burras mountains I found only the Alternating beds, which have there a very considerable thickness, and closely resemble the beds in the Colorado section, both in the character of the rocks and in the fossils, including the beds of *Requienia texana*, Roemer.

I did not find that these Glen Rose beds cut through at any point in the mountains visited, but, in all probability, the Trinity sands will be found underlying them, being indicated by the occurrence of springs in the various canyons.

*Episodes of the Bosque Period.*—In the Bosque period, therefore, the conditions seem to have been the same over the entire Texan area. The encroachment of the sea was from the south over a gradually subsiding sea-bottom. The advancing shoreline is marked by the deposits of Trinity sands accompanied and followed, in the deepening waters, by the Glen Rose beds, which, while of considerable thickness toward the south, decrease and finally wedge out toward the north, passing imperceptibly into the Paluxy sands, which are the latest deposits of the period, and, with the thin bedded marly limestones of the south, mark the shallowing waters of its close.

### *FREDERICKSBURG DIVISION.*

*West of the Pecos River.*—West of the Pecos river the Fredericksburg division has its most meager development along the Texas and Pacific railroad. At Kent it is not more than 50 feet in thickness, and in the vicinity of Sierra Blanca it is only 40 feet thick. Generally the Comanche Peak beds are missing, and the Caprina limestone rests immediately on the *Exogyra texana* bed.*

*In the San Lorenzo Section.*—In the Arboles mountains there is no apparent break in the sedimentation between the Glen Rose beds and the *Exogyra texana*, and the only means of determining where the one ends and the other begins is by the disappearance of the comparatively smooth and small form of the *Exogyra* of the former and the appearance of the better known *E. texana*, which gives its name to the latter.

The *Exogyra texana* beds and the overlying Comanche Peak beds present little or no variation in the San Lorenzo section from their normal character. The Caprina limestone, however, has an extraordinary thickness and presents some differences in the distribution of the fossils. The limestones of this stage are massive and cherty, as usual, but the *Caprina crassifibra*, which at all other localities examined appears in continuous bands, occurs here in nests and at several different horizons. Between horizons of the Caprina limestone, in the lower part of the beds, are bands

* For details see Second Ann. Rep. Geol. Survey of Texas, p. 717.

containing a *Gryphæa* in considerable numbers. This occurrence has its only analogue in a band of *Exogyra texana*, Roem., which occurs in the upper portion of the Caprina limestone on Barton creek, near Austin. Near the top of the Caprina limestone, and above the last bed of *Caprina* observed in this division, a bed of sponges was found. The only similar occurrence with which I am acquainted is in the Double Mountain section, and there the fossils are not so clearly distinguishable. The total thickness of the *Caprina*, as given by barometric readings, was 650 feet, but it may be found still thicker at other places in the mountains.

*Caprina crassifibra as a Criterion of Fredericksburg Age.*—While the presence of *Caprina crassifibra* cannot be taken as conclusive evidence of the Fredericksburg age of the beds in which it is found, since this fossil also occurs abundantly in the Washita, yet in this instance the character of the rocks of the two divisions is so different that there is little danger of mistaking one for the other, the Fredericksburg being much darker in color and more highly metamorphosed than the Washita, which here seems to rest upon it unconformably.

*The Kent Locality.*—The Caprina limestone was not found at Kent, the only member of the Fredericksburg which was positively identified being the Exogyra texana, with such fossils as *Ostrea crenulimargo*, Roem.; *Gryphæa pitcheri*, Mort.; *Exogyra texana*, Roem.; *Schloenbachia peruvianus*, von Buch. Whether the absence of the Caprina was due to the overlapping of later beds or to erosion prior to their deposition is not known, but it is probably due to the latter cause.

## *WASHITA DIVISION.*

*In the Trans-Pecos Area.*—This division, which in the Colorado River section attains a maximum thickness of 320 feet, finds in the Trans-Pecos area a far greater development, reaching a thickness of nearly 6,000 feet in El Paso county. Here, too, it gives evidence throughout its whole extent of being a deposit laid down in comparatively shallow water on a gradually subsiding sea-bottom.

*At the Kent Locality.*—At no place is this gradual subsidence more plainly shown than around Kent, where the Fredericksburg and Bosque divisions were evidently subjected to considerable erosion and some disturbance prior to the deposition of the Washita, and we find the lower beds of the Washita resting upon the Fredericksburg, while the higher beds overlap farther and farther on the Bosque sands. The rocks here are principally clays, marls and marly limestones; but in the beds of this division on the northwest side of Gomez peak a bed of limestone was observed containing a considerable quantity of silicious pebbles. The fossils are very abundant and well preserved.

The Exogyra arietina clays were not found at this locality, unless they be represented here by the beds containing the very similar form of *Exogyra plexa*, Cragin.

In the bed of a stream a few miles southwest of Kent there is an exposure of a fine white marble with reddish spots, which is lithologically similar to the Vola limestone. It contains great numbers of a large fossil which in general shape, size and appearance closely resembled the *Vola roemeri* of Hill, but they were all so worn that certain identification could not be made. In the upper portion of the beds were two or three bands which were simply masses of *Nerinea volana*, Crag., beautifully preserved in calcite. A good collection of these was made by Mr W. F. Cummins and myself. The stratigraphic relation of these beds to those of the Kent section was not traced, but beyond doubt they are referable to the Vola limestone. The thickness is much greater here than in the eastern exposures.

*Devils River Section.*—In the Devils River section, at the base of the Washita, there is a very sandy limestone, which in places carries considerable bituminous matter, especially in its upper portion. This sandy limestone is water-bearing and furnishes many good wells. It is overlaid by a semicrystalline, heavy bedded limestone, which carries, together with such characteristic fossils as *Schloenbachia leonensis*, Con., and *Kingena* (*Terebratula*) *wacoensis*, Roem., a bed of *Caprina crassifibra*, Roem., which in size of individual fossils greatly exceed any I have seen in the *Caprina* beds of the Fredericksburg. The exact relationship of these beds is well shown in some of the bluffs of Devils river northwest of Del Rio. One of them, by barometer measurement over 200 feet high, had at its base the large *Pecten texana*, Roem., of the Washita, about 70 feet above this a band of fossiliferous limestone containing *Kingena* (*Terebratula*) *wacoensis*, Roem., and *Schloenbachia leonensis*, Con., while at the top of the bluff there is a massive bed of *Caprina crassifibra*, Roem., with an echinoderm which, although badly weathered, seemed to be a *Pyrina*. Succeeding the *Caprina* bed, as shown by exposures southeast of this locality, the limestones are more marly and carry an abundant fauna of species characteristic of the Washita, and are finally succeeded at Del Rio by the Exogyra arietina clays and their capping of the Vola limestone.

*In the San Lorenzo Section.*—In the San Lorenzo section, in Coahuila, the Washita forms the surface rock of a large part of the area, being overlaid by the Upper Cretaceous only in places very near the river. The Washita has the sandy, water-bearing bed at its base, and this is capped in places by asphaltic limestones. The overlying limestone is semicrystalline and very light in color. The only fossil found was *Ostrea carinata*, Lam.

The Exogyra arietina clays and shales have a thickness of 140 feet, and are as fossiliferous as usual. They occur only near the Rio Grande. The change from the clays, shales and flags, which constitute these beds, to the massive and somewhat cherty Vola limestone, which overlies them, is abrupt. The Vola has its usual color of creamy white flecked with red, and has a thickness of 80 feet. In places it is almost a saccharoidal marble, and is better developed here than anywhere that I have seen it, except at Kent. Its characteristic fossil, *Vola roemeri*, Hill, was found in the bed of El Soro creek.

*The Finley-Eagle Mountains Section.*—The section between Finley and the Eagle mountains gives the greatest thickness yet observed in the Washita limestone. It is a region of long continued disturbance and volcanic activity, and the entire section has not been found in any one locality, so that the exact relations of some of the beds described are not certain, though the section, as a whole, is approximately correct. Here, too, is shown the greatest variability in the deposits, due to the oscillation of the sea-bottom. Toward the Eagle mountains the limestones are somewhat marly and carry an abundant fauna, as shown by the collections of Mr W. H. Streeruwitz. Just south of Sierra Blanca are alternating beds of sandstone and flags, with a thickness of over 4,000 feet, *Exogyra americana*, Marcou, being the only fossil found by me. This is the upper part of the division, and the lower rocks are probably overlain by the later sediments which cover the flat lying between this and the Caprina ridge north of it. In this lower portion, as exposed elsewhere, is repeated the occurrence, noted on Devils river, of the *Caprina* above what was formerly considered its culminating point in the top of the Fredericksburg, but here it is accompanied by a number of *Caprotina* forms. The rock-materials: sand, grits, conglomerates, limestones and beds of gypsum still indicate the oscillating character of the sea-bottom.

Around Eagle Flat station, and between that point and the Diabolo mountains to the north, the limestones are very arenaceous, and are capped with a sandstone which I have previously referred to the Dakota.

*Comparisons with other Localities.*—From the observations made it would appear that certain fossils which occur at one horizon in the Colorado-Red River section are found at entirely different horizons west of the Pecos. One of these is *Exogyra plexa*, Crag. In Williamson county this fossil is found in the base of the Washita limestone, if not in the Kiamitia clay, and it is also found at about the same horizon on Duck creek, in Grayson county, while in the Kent section it is more than 300 feet above the base of the limestone and overlies fossils which are found above it in the Colorado section. The recurrence of *Caprina* and *Caprotina* forms has already been noted, and the persistence of these forms from the Glen

Rose beds into the Washita is additional evidence of the unity of the deposits grouped together as the Lower Cretaceous series. The recurrence of so characteristic a fossil as *Gryphæa dilatata*, of the Jurassic, in its varietal form of *G. tucumcarii*, Marcou, in the base of the Washita, at Kent, has also been noticed.*

Another case is that of *Exogyra arietina*, Roem., which, even as far west as the Pecos, overlies the Washita limestone, while in the Sierra Blanca section it is, according to Taff, within 100 feet of the base. In the Malone mountains I found the *Nodosaria* bed, which is part of the *Exogyra arietina* beds, underlying a *Caprina* bed, and Taff found the same relation existing at the south end of the Quitman mountains. *Kingena* (*Terebratula*) *wacoensis*, Roem., is a form which, in the Austin section, belongs immediately below the *Arietina*. I found a *Terebratula*, in nowise distinguishable from it, below the *Caprina* bed of the Devils River section as well as above that bed, and it ranges from bottom to top of the Kent section. It was collected in quantities by Mr Streeruwitz from Devils ridge, just west of the Eagle mountains. While it is easy to distinguish two or three very different forms, such as an elongate form and another which is nearly as broad as long, these are not confined to separate horizons, but occur in the same bed, and when a sufficient number have been collected all intermediate stages can be readily found in them.

## Upper Cretaceous.

### *GEOLOGIC SUCCESSION AND CORRELATIONS.*

My first section of the Rio Grande Cretaceous, in "Notes on the Geology of the middle Rio Grande,"† gives the general succession of beds between Del Rio and the Cretaceous parting near the Maverick-Webb county-line. The divisions there given were based principally on lithologic grounds, although paleontologic differences were also noted.

Beginning at the base, the Val Verde flags, which were found overlying the Vola limestone, were considered the equivalent of the Eagle Ford or Benton shales (no trace of Dakota fossils having been observed). The overlying Pinto limestone was evidently the continuation or the equivalent of the Austin limestone, both lithologically and paleontologically. The Upson clays, corresponding both in material and fauna with the Ponderosa marls, followed, and were in turn succeeded by the San Miguel beds, which were the supposed equivalents of the Glauconitic or Navarro beds of the East Texas section. A subsequent study of a portion of the fossils of the San Miguel beds by Dr C. A. White confirmed this, and he

* See Am. Geologist, November, 1893, pp. 309-314.

† Bull. Geol. Soc. Am., vol. 3, pp. 219-230.

decided that they belong to the Ripley. In the East Texas section the Navarro or Glauconitic beds are the highest beds recognized. In the Rio Grande section the corresponding beds are near the middle of the section, being overlaid by nearly 4,000 feet of deposits of Cretaceous age.

This 4,000 feet I separated into two stages, the Coal series and the Escondido beds, and grouped all of the beds above the Pinto limestone as the Eagle Pass division. Under the names proposed and used by Dr White * for the divisions of the Upper Cretaceous the section given would be as follows:

Montana division = Eagle Pass division.
Colorado division = Pinto limestone and Val Verde flags.
Dakota division. Not observed here.

It is, of course, entirely possible that the basal portion of the Val Verde flags represent a part of Dakota time.

While it may be impossible to draw the line closely between the representatives of the Fox Hills and Fort Pierre stages in this region, I have placed it provisionally at the contact of the Coal series and Escondido beds, where we have the final disappearance of the *Exogyra costata*, Say, which extends in its varieties throughout the beds thus defined as Fort Pierre, and the first appearance of *Sphenodiscus lenticularis*, Owen.† This is the characteristic fossil of the Escondido beds in this section and is found in large numbers along the Rio Grande, from just below Eagle Pass to the southern line of Maverick county. Such a division places all of the Texas Cretaceous coals, whose horizons have been determined, in the Fort Pierre stage or subdivision.

### *DAKOTA DIVISION.*

My first reference ‡ of certain sandstones in the vicinity of Eagle Flat to this horizon has since been verified by the fossils found in them and extended by Taff in his Carpenter Spring section.§ No other exposures have been recognized. On Soro creek, in northern Coahuila, the Eagle Ford flags rest directly on the Vola limestone.

### *COLORADO DIVISION.*

The Eagle Ford clays were found by Taff and the writer in the Eagle mountains, as has been noted in the First and Second Annual Reports of the Texas Survey.

* Bulletin 82, U. S. Geological Survey.
† Cragin: Fourth Ann. Rep. Geol. Survey of Texas, part ii, p. 245.
‡ First Ann. Rep. Geol. Survey of Texas, p. xlviii.
§ Second Ann. Rep. Geol. Survey of Texas, p. 734.

In the middle Rio Grande section they are lime flags, separated by thin bands of laminated clays, and contain Inocerami and fish remains.

On Soro creek, west of Del Rio, they are also flaggy, but somewhat more arenaceous as well as bituminous. Inocerami were the only fossils found here.

At this locality the contact between the Vola and the Eagle Ford beds is well shown, and there seems to be absolute conformity between them. The Vola limestone shows no sign of erosion previous to the deposition of the Eagle Ford, but stretches along as a perfectly plain surface through an exposure of several hundred feet.

Above the Washita beds, on the northeast side of Gomez peak, near San Martine, there are beds of shaly to flaggy limestones belonging to this stage.

At only three localities have I been able to determine the presence of beds equivalent to the Austin limestone. It was found well developed in the middle Rio Grande section, and it was recognized at two localities in the Davis or Apache mountains. One of them was a small remnantal patch near Apache spring, just opposite the ranch-house of the Newman brothers. This was a bed of *Gryphæa vesicularis*, var. *aucella*, Roem., with *Ostrea congesta*, Con., a large *Inoceramus* and an unknown oyster. It was also recognized near Gomez peak, at the locality mentioned above, overlying the Eagle Ford shales.

### *MONTANA DIVISION.*

*Its Importance.*—This division is probably the most valuable, economically, of all the west Texas Cretaceous, and, when the entire section is made out, it may prove to have as great, if not a greater, thickness than the Washita.

*Areas investigated by the Author.*—The only two areas in which these beds have been examined by the writer are along the middle Rio Grande, the rocks of which were described in the paper referred to above, and a district in Presidio county, lying between the Viejo or Rim Rock mountains and the Rio Grande, which, as it includes the San Carlos coal mines, will be here described as the San Carlos section.

This area is situated twenty-eight miles by wagon road south of Chispa and eight miles from the river. The valley is rendered extremely picturesque by its bright colored rocks and the beautiful forms into which they have been carved by the combined effects of faulting and erosion. Four miles to the east of the San Carlos camp the Rim Rock or Viejo mountains rise to a height of 2,700 feet above the valley, the upper 200 or 300 feet being a vertical wall of trap, with columnar structure, in which single columns of 150 feet are clearly defined. The mountains, running north

and south, form a land-locked valley, which is further inclosed by ranges on the Mexican side of the river.

All of the sedimentary rocks which are exposed, except possibly number 2, belong to the Fort Pierre, but to the west are many white hills which may belong either to the Colorado or Fox Hills.

*General Section.*—The following is a general section from the more detailed one made by Mr Cummins and myself. The measurements are from readings of aneroid barometers and are approximately correct:

| | Feet. |
|---|---|
| 1. Lava-flow; rim rock of mountain | 200–300 |
| 2. Interbedded sandstones of various colors with calcareous clays and volcanic ash | 550 |
| 3. Conglomerate, resting unconformably on 4 | 1– 16 |
| 4. Lava-flow; apparently conformable on 5 | 50 |
| 5. Interbedded brown and red sands, purple shales and yellow quartzitic sandstone | 500 |
| 6. Gray and purple shales with thin strata of sandstone | 200 |
| 7. Coal shales with beds of laminated sands and two seams of coal; highly fossiliferous between and below the coal seams | 800 |
| 8. Interbedded sands and sandstones, some highly calcareous; fossiliferous | 250 |
| 9. Shales with concretions of clayey limestone containing fossils | 175 |

This gives a total thickness of over 2,800 feet.

*Fossils.*—The fossils contained in numbers 7, 8 and 9 are very abundant and well preserved. From the large collections made a suite was sent Mr T. W. Stanton, of the United States Geological Survey, for determination. He reports the following species:

1. *Nautilus dekayi*, Morton.
2. *Schloenbachia delawarensis*, Morton.
3. *Schloenbachia*, (?) n. sp.
4. *Baculites asper*, Morton.
5. *Baculites ovatus*, Say.
6. *Placenticeras guadalupæ*, Roemer.
7. *Heteroceras*, sp. undet.
8. *Hamites*, two species, possibly new.
9. *Turitella trilira*, Con. var.
10. *Strepsidura interrupta*, Con. (?)
11. *Gyrodes*, sp. undet., cf. *G. infracarinata*, Gabb.
12. *Volutomorpha*, n. sp. (?)
13. *Ostrea elegantula*, Newberry.
14. *Exogyra costata*, Say var. This particular variety, intermediate between typical *E. costata* and *E. ponderosa*, occurs in the Eutaw group and in the lower part of the Ripley, in Alabama, always at a lower horizon than true *E. costata*.
15. *Pinna*, sp. undet. Resembles *P. loquata*, Con., of the Ripley.
16. *Inoceramus cripsi*, Mantell.
17. *Trigonia thoracica*, Morton.

18. *Cardium alabamense*, Gabb. = *C. multistriatum*, Gabb. This species was also collected by Professor Cummins in 1889 across the Rio Grande river from Presidio.
19. *Cardium tenuistriatum*, Whitfield (?)
20. *Cyprimeria*, n. sp. (?)
21. *Liopistha*, sp. undet. Related to *L. protexta*, Con.
22. *Liopistha* (*Cymella*), sp. undet.
23. *Pholadomya*, sp. undet. Resembles *P. roemeri*, Whit.
24. Teredo (?) tubes.
25. An undescribed coral.

Mr Stanton adds the following note:

"While the fauna as a whole is closely related to the Ripley (Navarro) fauna, several of the species, and especially the ammonites, are not known to range so high elsewhere. I regard the *Exogyra*, the *Placenticeras guadalupæ*, and the two species of *Schloenbachia* as especially important in determining the horizon as lower than Ripley. The preponderance of evidence in the collection indicates that it comes from a somewhat lower horizon lying somewhere between the Navarro beds and the Austin limestone—that is, within the Ponderosa marls and probably pretty well down in them."

A good specimen of the tooth of *Ptychodus mortoni*, Ag., was also found.

*Dikes.*—The valley is intersected by two series of dikes, one striking north and south, the other and later east and west. They probably represent the fissures through which the two lava-flows of the mountain welled up to the surface, although we found no immediate connection between them.

In one place where the coal seam is cut through by a dike the coal is coked, but usually the metamorphism of the rocks along their courses extends only a small distance on either side.

*Folds, Faults and Lava-flows.*—Monoclinal folds are beautifully developed in this valley, with the same strike as the later dikes. The great San Carlos fault, west of the camp, has a throw of over 2,300 feet, bringing the upper lava-flow nearly to the level of the valley. The strike of the fault is north and south and its downthrow is to the west.

There seems to be an approximate synchronism between these lava-flows and those of the Shumard knobs. The volcano of Pilot knob, south of Austin, was active during the later stages of the Austin limestone, and probably continued well into the Ponderosa, and since no erosion was observed in the bed immediately underlying the first lava-flow, this lava of the Viejo mountain is also seemingly of Ponderosa age.

From the San Carlos and Balcones faults it is evident that these lines of eruption continued to be lines of structural weakness long after the dikes and lavas themselves had cooled. Thus the main Balcones fault

has a direction closely approaching that of the later of the systems of dikes, and the nearly north-and-south direction of the Cretaceous-Tertiary contact in Maverick county is probably due to a monoclinal fold of the Cretaceous similar to those observed west of it. This gave rise to an embayment in the Tertiary which stretched northward nearly or quite to Uvalde, which may well be called the Nueces embayment, since that stream now drains the entire area of the present surface exposure of these deposits.

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# HIGHWOOD MOUNTAINS OF MONTANA*

BY WALTER H. WEED AND LOUIS V. PIRSSON

*(Presented before the Society December 27, 1894)*

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## Part I.—Geology of the Highwood Mountains.

### *SITUATION.*

The group of mountains of which a brief account is given in this paper form one of the detached mountain groups lying east of the Rocky Mountain Cordilleras and rising abruptly from the level plains of central Montana. A glance at the map of the state shows the Missouri river, born of the Jefferson, Madison and Gallatin, in the mountain-encircled Gallatin valley, cutting its way in a general northward course through the outer ranges of the Rocky mountains until it debouches on the great open plains of the northwest. From here it turns in a rude arc, flowing eastward over the cataracts which have given rise and name to the city of Great Falls, and past Fort Benton, the head of steamboat navigation. In this arc, between the Missouri and the Little Belts, a front range of the Rocky mountains, the Highwood mountains are enclosed, and they are about 30 miles east of Great Falls and 25 miles south of Fort Benton. From each of these cities the peaks of the range form the most conspicuous feature of the landscape and break the monotonous level of the plains. The meridian of 110° 30′ west longitude and parallel of 44° 30′ north latitude pass through their center.

It is not proposed in this brief paper to present more than the salient features of the mountains as revealed by the field-work of the past summer, when the region was studied while mapping the geology of the Fort Benton sheet of the geologic atlas of the United States Geological Survey.

Previous knowledge of the geology of this mountain group is confined to a few notes published by W. M. Davis and W. Lindgren, who were at that time members of the Northern Transcontinental Survey.* These observers recognized the fact that the mountains were largely formed of Cretaceous strata penetrated by intrusions of igneous rocks. Later papers

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* Tenth Census of the United States, vol. xv, p. 734.

by Lindgren* give the results of very careful and detailed petrographic studies of several rock specimens from this field. These studies show that from a petrologic standpoint the rocks of this district are of great and unusual interest.

### *GEOGRAPHY AND TOPOGRAPHIC CHARACTERISTICS.*

The Highwood mountains form a distinct unit in the geography of Montana. The front of the Rocky mountains, formed of the Little Belt range, lie to the south of the group, with a broad, flat and open valley between, while the Judith and Big Snowy ranges fill the horizon to the northeast. Standing alone and rising abruptly from the flat Cretaceous plains, the mountains possess an imposing appearance hardly warranted by their height. The 300 square miles of highland forming the group is some 25 miles long from east to west, with a breadth, or north-and-south direction, of from 15 to 16 miles. The loftiest peaks, Highwood and Arrow, reach a height of 7,600 feet above tide, or 4,000 feet above the plains which sweep away in monotonous continuity from the foot-slopes.

From most points of view the mountains are seen to consist of a gently contoured, rounded group of comparatively low peaks forming the northern half of the group, rising gradually and culminating in the higher rugged crests which constitute the southern part of the cluster. A striking feature is a deep cut, drained by Arrow and Highwood creeks, which separates the mountains into east and west portions and forms a pass known as Highwood gap. While the main mass consists of an irregular collection of peaks connected by high ridges which make a topographic whole, there are also two buttes lying east of the mountains which are a part of the group. The easternmost is a flat-topped mountain mass, rising to an elevation of nearly 6,000 feet and forming the most salient feature of the landscape wherever visible. This is Square butte, an eminence as important geologically as it is prominent topographically. Between this and the main ridges of the mountains rises the dark pillared form of Palisade butte, the other of the two.

Surrounding the range on every side is the open plains country, cut into picturesque badlands along the Arrow river, but elsewhere preserving that persistent horizontality so characteristic of the Great plains of the northwest. Rising abruptly from this level area, the mountains act as local condensers, so that the slopes are well watered; thunderstorms are common during the summer, and the higher peaks generally cloud-enveloped for a large part of the year. Although not of sufficient height to maintain permanent snow banks, the mountains give rise to several fine streams, which head in springs far up the narrow V-shaped trenches

* "Eruptive Rocks from Montana." Proc. California Acad. Sci., ser. 2, vol. iii, 1890, p. 39; also, Am. Jour. Sci., vol. 45, 1893, p. 286.

which everywhere score the higher elevations. This abundance of moisture favors agriculture, and the upland valleys and mountain foot-slopes are occupied by ranches. The cereals and a great variety of vegetables not commonly raised in the State are grown and reach maturity despite the short season. The surrounding country is very generally given over to raising cattle or sheep.

### *GENERAL GEOLOGIC STRUCTURE.*

The Highwood mountains consist of the denuded remains of a group of volcanoes whose rocks show extreme differentiation of a highly alkaline igneous magma. They contain several volcanic cores or conduits, now filled with massive granular rock. These are surrounded by tuffs and volcanic breccias, with lava-flows, and great numbers of radiating dikes.

The main mass of the mountains consists of basaltic breccias, resting upon Cretaceous sediments and the earlier acidic tuffs and breccias, which form the foothills to the east and northwest. The metamorphosed sedimentary rocks about the volcanic cores form a lesser but prominent feature, as their resistance to erosion has left them as important peaks. In approaching the range, the great number of dikes which stand up as walls, extending often for miles across the level bench land, form a conspicuous and most interesting phenomenon. On the lower mountain slopes they are even more numerous, and easily suggest that the mountains themselves are of sedimentary rocks penetrated by dikes and igneous masses. The radial disposition of the vast number of these dikes is one of the most marked characteristics of the geologic structure. From the summit of South peak they may be seen radiating outward, traceable with a glass for miles, over the open grass-covered country below. Even those composed of rocks which weather readily to the general level can be traced by the grass and herbage on their outcrops, for the soft, sandy soil produced by their decomposition is markedly different from the soils of the Cretaceous rocks, and the difference is accentuated by the plant growth. Often, moreover, these dikes have baked the adjacent rocks and both edges of the contact are marked by narrow lines of hardened and generally bare outcrops.

From the crest of South peak, owing to the above facts, the course of the dikes can be traced over the open brown slopes as rough black walls of projecting rock, vivid bands of green or by parallel bands of dark color appearing like long lines of sepia drawn on a surface of brown paper.*

The view from the summit of Palisade butte or of Alder peak is even more remarkable. Here the dikes appear as massive stone walls, from

*See also Davis, loc. cit.

6 to 10 feet wide and of varying height, which cross the country in great numbers, and are clearly seen to converge toward a common center. As many as 70 distinct and separate examples were observed in one view.

These relations are presented on the accompanying geological map (see figure 1), which shows the areal disposition of the varied rock masses composing the mountains.

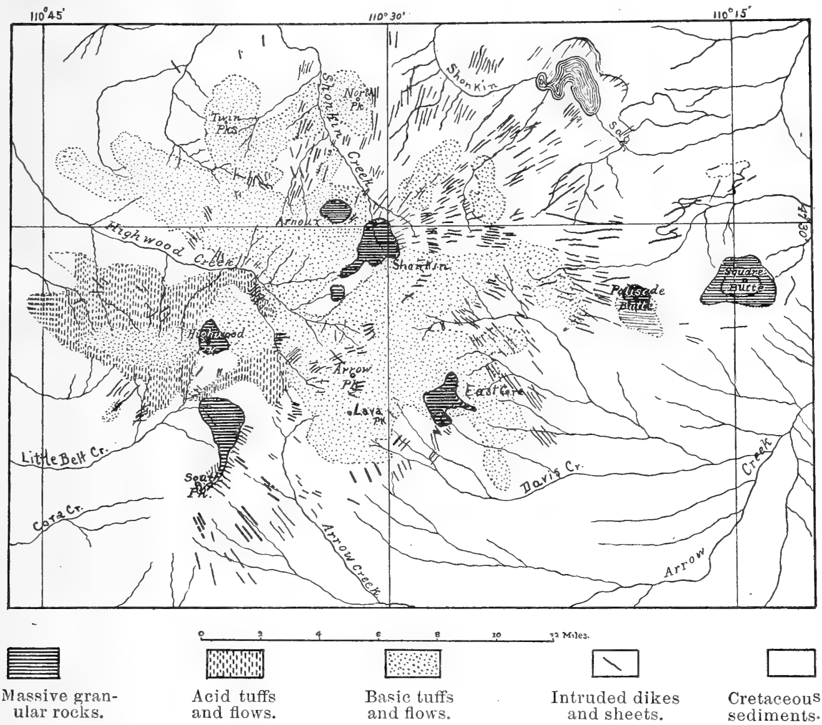


FIGURE 1.—*Geological Map of the Highwood Mountains, Montana.*

### *THE SEDIMENTARY PLATFORM.*

Although the chief interest in the Highwood mountains lies in its igneous rocks and their relations, a few words on the sedimentary beds will be necessary.

The sedimentary platform on which the mountains rest is formed of soft Cretaceous strata. The general expression of the platform is that of a continuous level plain, but the topographic details possess considerable variety. The radiating streams from the mountain amphitheaters have trenched the soft rocks, producing canyons which separate long tables of nearly level prairie. So abrupt are these gorges that in approaching even the largest of them, the valley of Belt creek, no indication

of a break in the continuity of the plain is given until within a few feet of the canyon wall.

About the mountains there are occasional remnants of higher levels, forming bench-like steps. To the north the extension of the gentle outward slope of the platform away from the range is interrupted by the Shonkin Sag, an old drainage-way which marks the southern limit of the moraine of the Laurentide glacier. The open country between the mountains and the Belt range is a very wide, shallow valley rather than a plain. The strata composing the platform are in general horizontal or but slightly inclined away from the mountains. The exceptions are the beds just east of Highwood gap, at the debouchment of Shonkin creek, and in Davis creek valley, in each of which places local flexures occur. The strata west of the mountains dip gent'y away from the peaks.

The rocks themselves consist of sandstones and clayey shales belonging to at least two groups of the Cretaceous. The lowest series is exposed in this vicinity only in Belt creek, and consists of rather firm, well cemented sandstones, alternating with purple and red clays and shales. These beds are classed as Kootanie. Along the flanks of the Little Belt range this series rests in apparent conformity upon the fossiliferous Jurassic beds. It is the series containing the well known coal seam of the Great Falls field. The strata vary rapidly, sandstone beds ending abruptly and being replaced by shales. All the evidences show shallow-water conditions and shifting stream currents. The sandstones are rarely conglomeratic when the pebbles are of black quartzite, but the sand grains are angular and show little alteration by attrition. Plant remains from this series found near Great Falls at approximately the horizon of the coal seam were determined by the late Dr J. S. Newberry * as Kootanie, a later paper by Professor W. M. Fontaine † taking the same view. A small collection of plant remains collected by one of the authors from the coal seam south of the Highwoods proves to be of Kootanie or Lower Cretaceous age upon examination by Professor F. H. Knowlton.

The coal seam is the most important single seam in the state, and at Belt and Armington it is being extensively mined. The seam is from 6 to 8 feet thick, with several minor partings and a persistent layer of sandy shale which separates it into an upper and lower bench. The character of the coal from these two benches differs quite materially, the upper being a free-burning bituminous variety with high percentage of ash, the lower a coking coal with higher fuel ratio.‡ The latter alone is mined at Belt for the Butte smelters.

About 200 feet above the coal seam is a limestone layer, or more gener-

* Am. Jour. Sci., vol. xli, 1891, p. 191.

† Proc. U. S. Nat. Mus., vol. xv, 1892, p. 487.

‡ Weed: Bull.Geol. Soc. Am., vol. 3, 1892, p. 301.

ally, however, a stratum containing limestone nodules full of fresh-water shell remains. The species are not of specific value, consisting of *Viviparus* and *Goniobasis*, with Unios, but are of interest as indicating the fresh-water nature of the deposit.

The coal series of sandstones, clays and marly beds is overlaid by the dark carbonaceous shales referable to the Fort Benton, and containing fossils of that age at the base of the mountains. No Dakota is recognizable, either lithologically as the conglomerate, which forms so prominent a feature of the strata between Jurassic and Fort Benton sediments farther south, or paleontologically by fossils. If present, it is so like the underlying formation as to be indistinguishable from it.

In Belt butte, a prominent eminence rising above the benchland west of the mountains, the shale series is well exposed and appears of Fort Benton facies, although the sandstones indicate shallow-water conditions not shown by the Missouri River beds. The lower beds are black and deep purple shales, with occasional thin layers of sandstone. There is a prominent sandstone horizon forming the girdle or belt around the butte which is also a persistent horizon about the mountain flanks. Above it the shales are grayer in color, and the arenaceous varieties which succeed them carry large quantities of Ostreas.

The highest beds of the unaltered sedimentary series are white or light colored sandstones alternating with argillaceous strata, which on the north flanks of the mountains carry fresh-water fossils. This horizon is seen forming prominent bluffs along the east end of the Shonkin Sag and the higher bench of Square butte, and is probably the same bed seen capped by gray shales at Highwood gap. This sandstone is the highest horizon of unaltered rocks seen in the Highwoods. It is suggested that it may represent the extreme southward development of the non-marine Belly River formation, an infra-Fort Pierre group of coal-bearing rocks of the Canadian geologists.

About each of the volcanic cores of the Highwoods there are areas of highly altered metamorphosed sediments, which in South peak form the main mass of the mountain. These rocks have lost all trace of original bedding planes, and consist of dense hornstones, quartzites, etcetera, and only show in their present character that they were originally argillaceous and arenaceous shales. They cannot be distinguished in their present state from the baked Algonkian slates or altered Cambrian shales of Castle mountain or the Livingston beds of the Crazy mountains, features of local metamorphism in areas to the southward.

### *IGNEOUS ROCKS.*

*General Characters.*—The individual characteristics of the volcanic conduits are such as to warrant brief notes upon each eruptive center. A

considerable differentiation of magmatic material has taken place at each of them and the granular rocks now exposed present several types of interest.

*South and Highwood Cores.*—On the western side of Highwood gap there are two of these cores, and the most southern of them is the oldest center in the range. It is composed of an augite-syenite, and rises through level-bedded sandstones, which it has greatly indurated. Large numbers of dikes depart from its circumference radially in all directions. They are generally rather narrow and basaltic in character and of two prevailing types, one a possible leucite or analcite-basalt, with phenocrysts of leucite, (?) augite and olivine; the other type contains only very large plates of black biotite in a dense black groundmass. The "complementary" dike-rocks, to use the excellent term of Brögger, are porphyries, with large, thin, tabular phenocrysts of feldspar, which are much less common than the basaltic types.

This south core of massive rock is not surrounded by breccias or flows, those to which it possibly gave rise having been carried away by an amount of erosion sufficient not only to cut down the former cone en-

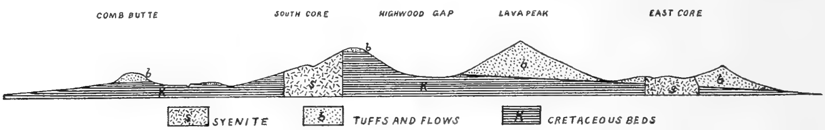


FIGURE 2.—*Cross-section through Highwood Mountains.*
Vertical and horizontal scales the same.

tirely, if such ever existed, but also to erode deeply into the level strata through which the former vent arose. This denudation left the strata as a small range, through which the later outbursts forced their way and whose slopes they covered with extrusive material. These outbreaks took place at Highwood peak, whose exposed core, denuded of its covering of ashes, tuffs, etcetera, now towers up as the highest and sharpest peak in the group.

During the period of activity of this volcano it emitted at first acidic, light colored feldspathic tuffs and breccias, intermingled with flows of felsite and possibly phonolite. These in turn were succeeded by ejections of very basic matter, which formed breccias and lavas of basalt similar to the South Peak dikes.

The Highwood core may be also said to be a syenite, but it presents a number of points of great petrologic interest, giving evidence of a remarkable amount of differentiation in place. It also is surrounded by a number of radial dikes similar in character to those mentioned before.

*East Core.*—The east core, at the head of Davis creek, appears to be still younger. It is still partly surrounded by the masses of basaltic

lavas and breccias which form the eastward extension of the range; it has also a small number of radial dikes. The accompanying figure, 2, presents a nearly east and-west section through Comb butte and Lava peak. It cuts the south and east cores and shows the accumulations of extrusive material resting on the horizontal Cretaceous strata.

*Shonkin Core.*—The northern half of the mountains is of lower general elevation than that to the south, and it is drained by the branches of Shonkin creek. Seen from a distance, the area is one of convex summits and gently contoured slopes, devoid of timber, but covered with a velvety nap of grass, giving the smooth, rounded effect of a topographic model. When visited this area is found to be deeply trenched by sharp V-shaped gorges, whose streams flow in rock-cut channels, which expose excellent sections of the geologic structure. On the west the long northwest spur of the mountains, terminating in Twin peaks, divides the waters of Highwood creek from Shonkin. This ridge shows only the dark basaltic lavas, generally fragmental, and similar to those which compose Arrow peak and the adjacent ridges. To the northeast outliers of the same basaltic lavas and breccias form mountain masses resting upon sedimentary ridges.

The valleys of the numerous branches of Shonkin creek are largely cut in sedimentary strata, which are everywhere penetrated by dikes whose parallel trend makes their dark walls, rising above the grassy slopes, all the more impressive.

The multitude of dikes in the foothills and benchland north of the mountains has already been noted. From Palisade butte westward to Twin peaks these dikes radiate from an area which examination proved to be the largest massif of the group. Radial dikes also occur in large numbers on the south and west of this center, but are less conspicuous and are associated with some which belong to the Highwood Peak system.

The Shonkin core is the largest one of the group. Denudation has as yet but partially stripped it of its covering of tuffs and breccias. The granular rock is, however, well exposed in the creek bed and the steep slopes on each side. This rock has broken through horizontal beds of sandstone and shale, which are greatly altered by contact metamorphism. An offshoot of the main body extends southwest under a cover of these altered beds to the slopes drained by Highwood creek. The streams which trench the slopes expose the massive rock which is also seen on the crest between the two drainages. At the latter place acidic tuffs and breccias rest on the sedimentary beds, and are at times very difficult to distinguish from them. The main body of igneous rock, as well as this offshoot, shows in its rapid variations considerable differentiation, though not so much as at Highwood peak. The rock usually weathers into

platy fragments, forming a talus slide, but rarely makes bold craggy masses rising abruptly from the slopes. Nowhere was the main body of granular rock seen cut by dikes.

An interesting feature of the Shonkin core occurs at its extreme southern end. Here there is what is believed to be a volcanic throat. The coarse grained rock occurs in great blocks, often with partially rounded edges, forming a coarse agglomerate whose matrix is a finer grained variety. The tumultuous arrangement of the agglomerate, the coarsely granular nature of the rocks, and the baking of the adjacent basaltic breccias all indicate a volcanic throat.

It is the only locality in the Highwoods showing evidence of solfataric decomposition, the rocks adjacent to the neck being altered and iron-stained. This neck represents probably one of the latest points of volcanic activity of the mountains, as it breaks through the basic breccias.

*Arnoux Core.*—This is a comparatively small core of granular rock breaking through acidic tuffs and basaltic lavas. There are a number of dikes traceable to this center, and it is surrounded by a ring of metamorphosed rocks. The core material resembles that of the Shonkin center, which is near by, and from which it does not differ in any essential characteristic.

*Palisade Butte.*—The eastward extension of the range is formed by two isolated points, Square and Palisade buttes. The latter and smaller of these stands about midway between the group of breccia hills which forms the eastern foothills of the main mountain mass and Square butte. It consists of a huge monolith of rock rising some 600 feet above the slopes at its foot, the whole mass having an elevation of about 1,000 feet above the plain on which it stands. The breadth across the isolated rock mass is about three-quarters of a mile and the shape is nearly circular. On the top it is not horizontal, but slopes downward from south to north at an angle. The rock mass rises abruptly above its pediment and fronts the plain on all sides in a series of bold precipices. These precipices are not, however, continuous either around the circumference or from top to bottom, being broken by a series of narrow, steep ravines which permit access to the summit.

The most striking feature of the butte is the magnificent columnar structure of the igneous rock composing it and from which it has received its name. The steep precipices composing the front are formed of a vast series of huge regular perpendicular columns, each of which rises regularly from the talus and continues to the top. These columns are some 18 inches in diameter and may be 150 to 200 feet high. They evidently once extended the whole height of the mass. The butte thus bears a striking resemblance to the well known Devils Tower in the northwestern part of the Black Hills region.

The rock composing these columns is very dark and heavy and of basaltic appearance, consisting largely of augite. It is rather coarsely crystallized and is the shonkinite described in the second part of this paper.

The top of the butte is a wedge-shaped mass of a light colored syenitic rock, the thicker portion turned to the south, where it forms a small cliff. It is made up of rather thin plates. Its exact relation to the dark columnar mass is somewhat uncertain, but as dikes were seen cutting the latter near the light rock it has probably been extruded through it. With respect to the butte as a whole, its relations to the horizontal sedimentary rocks through which it has been projected upward, together with its own structure and rock character, indicate clearly that it is the denuded remnant of a former volcanic plug or core.

*The Shonkin Sag Laccolite.*—North of Square butte the walls of the Shonkin Sag expose a beautiful section of a laccolite intruded in the sandstones of the Cretaceous series. The laccolitic rock forms massive pillars, whose dark color contrasts strongly with the white sandstones above and below. The exposed section of the laccolite is a mile and a quarter long and at least 150 feet thick. At each end the laccolite tapers in a blunt wedge, the covering of sandstones curving up very abruptly. There are several fringing sheets running out from the laccolite into the tilted beds and filling the interspaces formed by the folding. These sheets do not extend far from the main mass. The base of the laccolite is, however, prolonged in a sheet of perhaps 25 feet in thickness, which is exposed as a black band in the light colored cliff extending 5 or 6 miles from the laccolite.

## *GEOLOGIC HISTORY.*

The geologic history of the Highwoods may be briefly summarized as follows:

Volcanic forces breaking through the horizontal strata of a deeply trenched and partly dissected plateau formed a group of volcanoes whose eruptions, continued at intervals through a considerable period of time, resulted in the formation of great numbers of dikes and the accumulation of fragmental deposits and lava-flows. Subsequent denudation largely removed the materials forming the volcanic cones, exposing the granular rocks filling the old necks, while the remnants of the cones form the greater part of the mountains. To the eastward the earlier eruptions formed the laccolitic masses of Square butte and the Shonkin Sag laccolite. The group presents certain analogies to the Crazy mountains farther south, but differs from them in having surface flows and breccias.

With respect to the petrographic characters of the igneous rocks of the Highwoods, it may be remarked here that their study, which was made in the field, together with a preliminary examination made of thin-

sections, show them to be of novel types and of great interest from a petrologic standpoint. This is so especially true in the case of Square butte that we have already made a detailed study of the facts presented in this particular area and the results form part second of this paper.

## Part II.—Square Butte and its Remarkable differentiation Zone.

### *INTRODUCTORY.*

The relation which Square butte bears to the Highwood range has been briefly mentioned in part I of this paper, and it is clearly shown on the map on page 393. The range consists of a number of closely clustered peaks with two very conspicuous detached elevations, the larger and more easterly of which is Square butte. Although it is genetically and geologically part of the Highwoods, it is geographically a distinct and separate elevated mass. It is the most prominent landmark to be seen from the level lands which stretch far to the north and east, and its dark base and white crown make it conspicuous at a distance of 15 or 20 miles. The name it bears is of course derived from its flat top, which distinguishes it so sharply from the pointed peaks of the Highwoods.

Square butte was visited by the authors during the past summer, while studying the geology of the Highwood range, and found to possess certain peculiarities of structure and origin which render it, from the standpoint of broad petrologic geology, one of the most interesting occurrences of igneous rock which has ever been described.

### *HISTORICAL.*

The only published account of the butte is in a paper by Mr W. Lindgren and the late Dr W. H. Melville.* In this paper the butte is described as being composed of a light gray eruptive rock, having a distinct lamination, with several horizontal sheets of a dark volcanic rock intruded in the sediments around its base. Specimens of the light colored rock forming the upper portion which had been collected by Dr C. A. White were subjected to a very complete petrographic and chemical study, from which it was shown to be a peculiar member of the nephelite-syenite family of igneous rocks, consisting chiefly of a black, soda-rich hornblende (near barkevikite in composition), alkali feldspars and sodalite; in short, a sodalite-syenite. No other reference to the butte has been found by us in the literature.

### *GENERAL DESCRIPTION OF SQUARE BUTTE.*

Square butte is a rudely circular mass resting on a nearly level tableland, which has an elevation of about 4,000 feet above the sea. This platform consists of nearly horizontal sandstones and shales belonging

*Am. Jour. Sci., vol. xlv, 1893, p. 286.

to the Colorado group of the Cretaceous period. In the vicinity of the butte this tableland is deeply trenched by the Arrow river and its tributary streams, and in consequence it forms locally a broken country, affording excellent geologic sections and typical "badlands" scenery. At the base of the butte three intrusive sheets of the dark igneous rock mentioned by Lindgren occur in these sediments.

Above this flat, trenched tableland the butte rises abruptly to a height of 1,700 feet above its pediment. The slopes, at first gentle, change quickly to steeper declivities and terminate at the top, on all sides, by a precipitous wall several hundred feet high. Only in a few places is this escarpment cut by very small, narrow gulches, which permit difficult ascent to the top. The summit is a nearly level area, elliptic in outline and nearly one mile across in its greatest length. It is largely covered by a dense growth of small pine, with occasional park-like glades and openings.

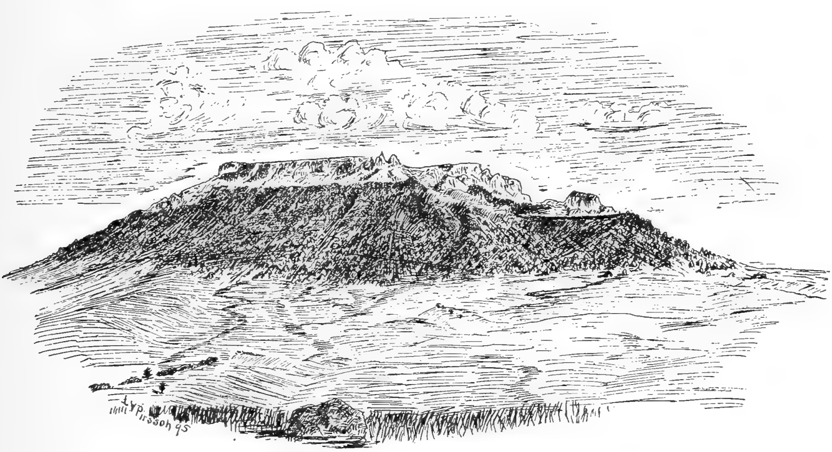

FIGURE 3.—*View of Square Butte from the Slopes of Palisade Butte.*

The quite symmetric form of the butte is rather remarkable. It presents from nearly every point the appearance of a very short section of a huge cylinder resting on a low, broad, truncated cone. This regular arrangement is interrupted only on the southwest side, where a short tongue-like protrusion of the mass occurs. The facts which have been stated are shown on the map accompanying the previous article (page 393), while they are presented in greater detail on a larger scale in figure 4 of the present paper. Figure 3 gives also a view of the butte from Palisade butte and shows well the tongue-like protrusion.

*ITS LACCOLITIC ORIGIN.*

A careful examination of the butte shows that it is composed entirely of igneous rock. Above the sandstones of the tableland no sedimentary

rock whatever is seen. Near the immediate contact of the igneous rock with the sedimentary strata the sandstone beds curve up sharply on all sides. Beyond this, where the trenching by the streams has gone on, the sandstones have been cut into and the intrusive sheets which form a peripheral fringe around the mountain are brought to light. These relations are shown on the map, figure 4, and by the cross-section, figure 6, page 407.

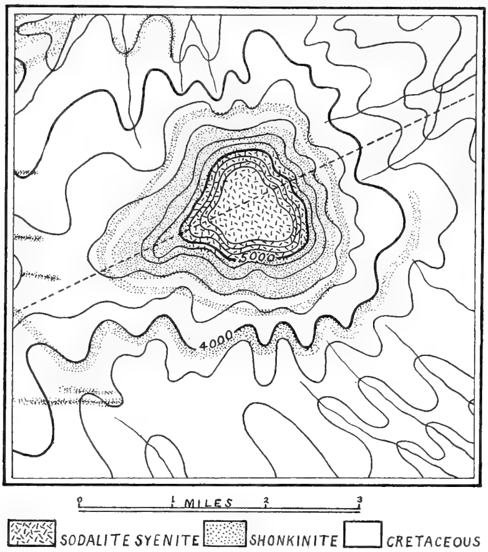


FIGURE 4.—*Geological Map of Square Butte.*

When we consider the form of the mass presented by Square butte, the ring of upturned sediments around it and a number of other considerations of structure, etcetera, which will be presented later, it is plainly evident that the butte is a great laccolite stripped of its sedimentary cover, but not yet sufficiently eroded to lose its general form. This interpretation of its origin is also supported by the occurrence to the eastward of Square butte of the laccolite through which the Shonkin Sag gives such a remarkable section, and which has been alluded to on page 399 of part I of this article.

### *LOWER ZONE OF DARK HOODOOS.*

Square butte is remarkably impressive, even from a distance. From every point of view it is seen to present, first, a base of dark, somber slopes, extending nearly half way to the summit, which in turn are capped by light colored ones that over great areas are often a glaring white. Within a few miles of the butte the dark base is seen to be most fantastically eroded into jutting towers and spires of rock, recalling the strange shapes given by weathering to the volcanic breccias and conglomerates of the Absaroka range and other portions of the Rocky Mountains region.

On approaching nearer the mountain one's attention is still more strongly fixed by these two peculiarities. The eroded base is seen to consist of a vast series of "hoodoos"* or forest of strangely shaped monoliths, which surrounds on all sides the lower slopes of the mountain and which die out at about a given height.

* See Century Dictionary, p. 2877.

FIGURE 1.—VIEW OF THE BUTTE FROM FOOT-HILLS ON SOUTHEAST SIDE.

Showing zone of hoodoos below and white syenite above.

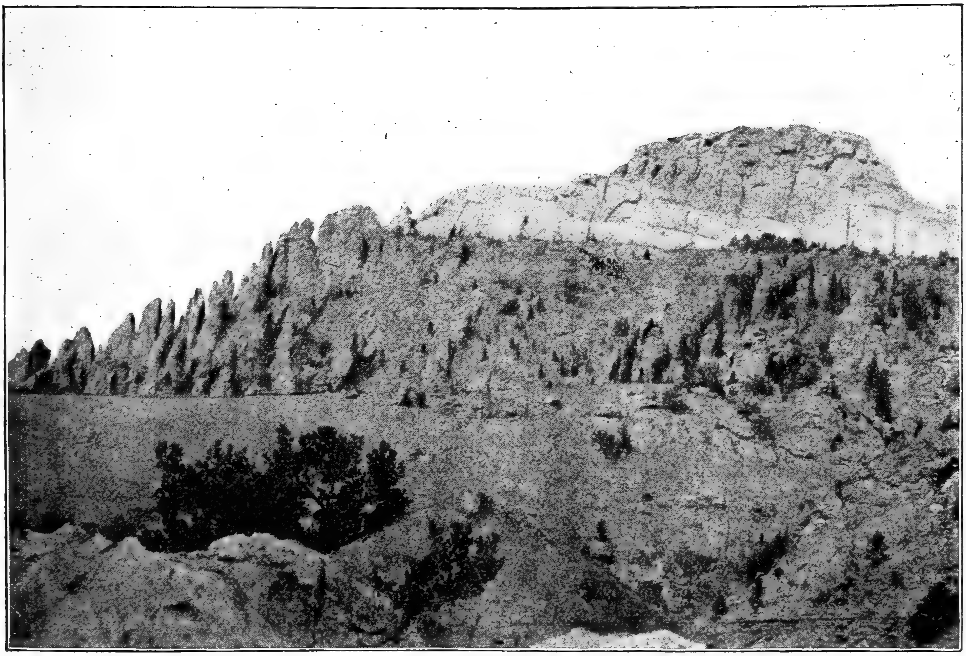

FIGURE 2.—SOUTHWEST END OF BUTTE SHOWING WHITE SYENITE ABOVE AND DARK SHONKINITE BELOW.

SQUARE BUTTE.

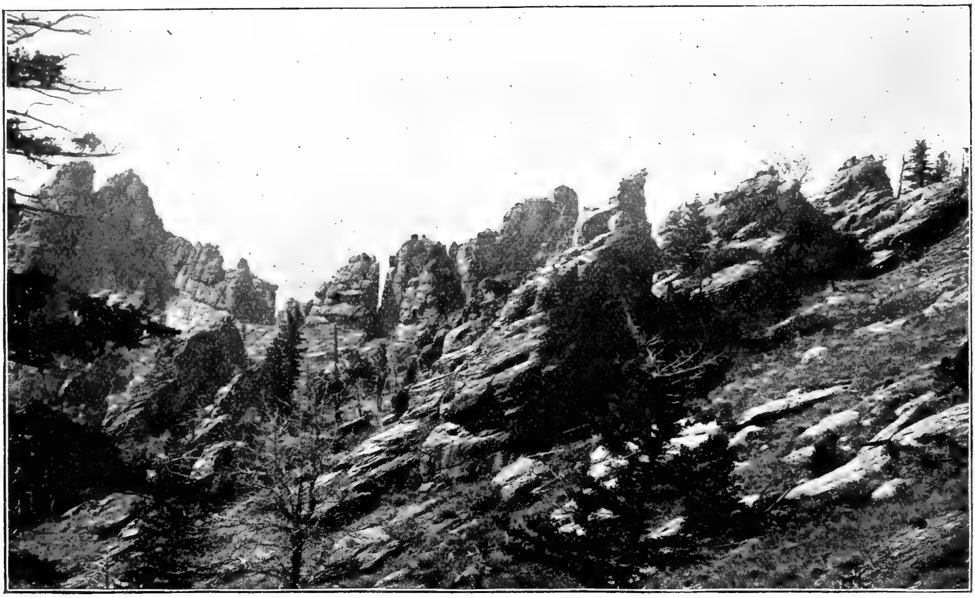

Figure 1.—Hoodoos of Shonkinite showing platy Parting and Dip.

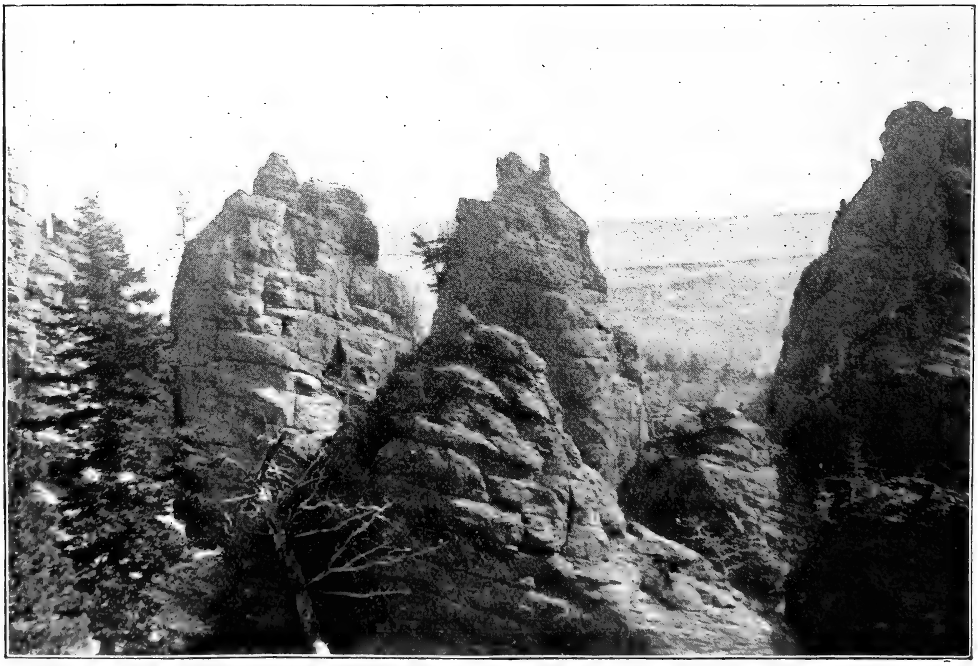

Figure 2.—In Zone of dark Hoodoos of Shonkinite on south Side of Butte.
Showing the disk-like structure.

SQUARE BUTTE.

Above this is seen the intensely white color of the naked upper slopes, masses and precipitous walls of rock which rise above the bristling fringes of hoodoos below, a contrast rendered all the more intense by the whiteness of the former and the black color of the latter. These peculiarities are shown by figure 1, plate 24, which is a view of the butte from the lower slope on the southeast side, and by figure 2, plate 24, which shows the south side of the prolongation on the southeastern side of the mountain and which has been previously referred to. It must be said, however, that the photographs present only in a feeble way what is most striking in nature.

As one approaches still nearer and enters the region of black monoliths, it is found to be a labyrinthine maze of small glens, separated by towering masses and pinnacles of black rock. The hoodoos attain in many places a height of from 100 to 150 feet, and from that sink in size down to examples but a few feet in height. The attention is immediately arrested by a peculiar and regular arrangement of a platy structure they possess. They are built of a series of inclined disks, each a few inches in thickness and oval to subangular in shape, and with rounded edges which accentuate the disk-like form. Generally the disks decrease in size from bottom to top, but there are many exceptions to this rule, and in these cases strange and weird figures are produced, resembling colossal statues, sarcophagi, etcetera. Occasionally the disks are not flat, but slightly dished; the hoodoo then resembles a pile of huge inverted watch glasses. The plane or hade of the disks is not horizontal, but slopes to the outside in all directions around the mountain approximately parallel to the prevailing slope, which, indeed, is conditioned by this platy parting. The disposition is precisely like the dip and strike of sediments in a domed anticline, and the resemblance at times to sedimentary strata is quite striking, as may be seen in figure 1, plate 25.

The hoodoos are apt to be disposed in radial trains around the mountain slopes, each train growing consecutively smaller as it ascends. Between them are the small wooded glens previously mentioned (see figure 2, plate 25).

The rock forming these strange pinnacles is uniformly in all cases a rather friable granular one, composed chiefly of a basaltic augite, to which their black color is due.

The origin of these spire-like masses is partly explained by the frequent presence of large, often huge, spheroidal bowlders of white syenite resting upon their points and often balanced in almost incredibly delicate positions. As these masses which descended from the upper slopes are hard, tough and feldspathic, they have resisted weathering and erosion much better than the crumbly, easily altered dark augitic variety upon which they fell, and have thus conditioned the construction of the pin-

nacles, just as rocks condition the formation of ice-tables and pinnacles on glaciers (see figure 1, plate 26).

In many other cases the white syenite bowlders are to be seen lying at the foot of the columns from which they have fallen.

We may remark here that in all our experience we have never seen a more weird and curious labyrinth of pillared rocks than this which surrounds the lower base of Square butte. In singular scenery it equals, if it does not surpass, the famous Hoodoo country, on the northeast border of the Yellowstone National Park, in northwest Wyoming.

### *UPPER ZONE OF WHITE ROCK.*

Ascending through the zone of hoodoos which measures perhaps a mile along the slope, they are found to diminish in size and a horizon is reached where the character of the rock changes abruptly from the dark, nearly black augitic phase to the white syenite described by Lindgren. In many places the hoodoos continue, but now they are made of the white rock. They are smaller in size, but possess the same remarkable disk like, platy structure, and the disks are perfectly parallel to those of the black variety below. The white hoodoos are rarely pointed, and are more apt to be flat topped and of the character seen in figure 2, plate 26.

The transition line between the two rock varieties is extremely abrupt, but it is not of the nature of a contact. The rock continues of even grain throughout, but in the space of a few inches or a foot or so the black augite begins to diminish and finally disappears, the rock assumes a more feldspathic character, hornblende occurs, and it rapidly passes into the syenite described by Lindgren and which constitutes the main inner mass of the mountain. There is thus a narrow mottled zone between the black and the white rock. The hornblende is present in so small an amount in the syenite that the rock, especially when seen in full sunlight, has the whiteness of marble.

The monoliths which lie near the transition zone are sometimes seen to be of black disks resting in place on a pediment of the white rock below; sometimes the transition band passes through them and they are of black disks resting on white ones, or it passes through the disks at a nearly vertical angle so that one part of each disk is white and the other black; at other times a white hoodoo is but a few feet distant and above a black one, both resting in place on a continuous exposure of the white rock. These facts are illustrated in figure 2, plate 26, which shows a black hoodoo resting on white syenite, with a white hoodoo above and to the left.

The facts just presented are to be carefully noted, because they show beyond the possibility of a doubt that however much the two varieties of rock may differ and however abrupt may be the change from one into

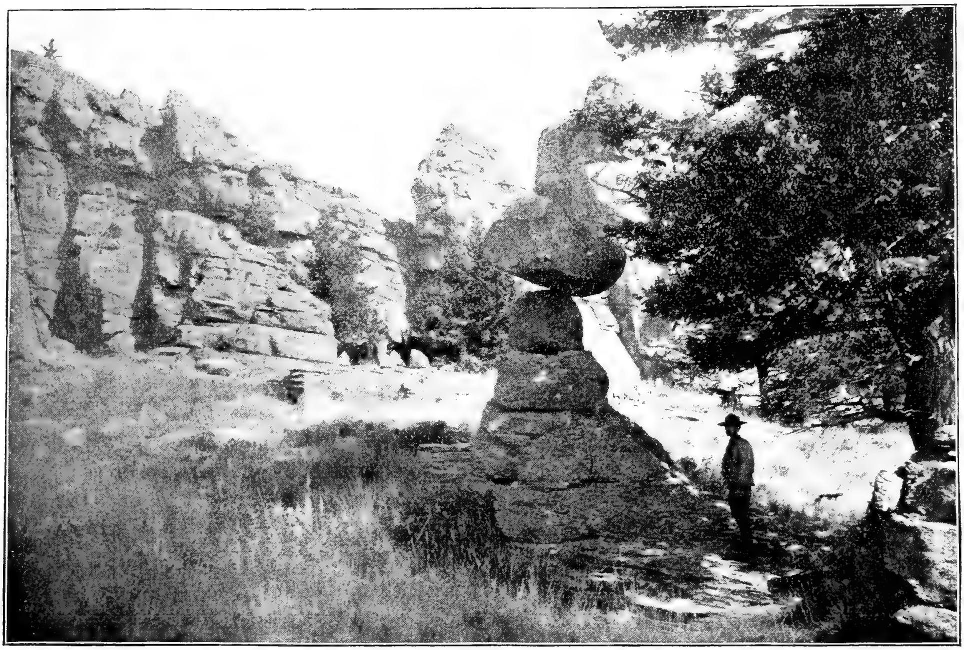

FIGURE 1.—BOWLDER OF SYENITE RESTING ON PILLAR OF DARK SHONKINITE.

In the zone of dark hoodoos, south side of butte.

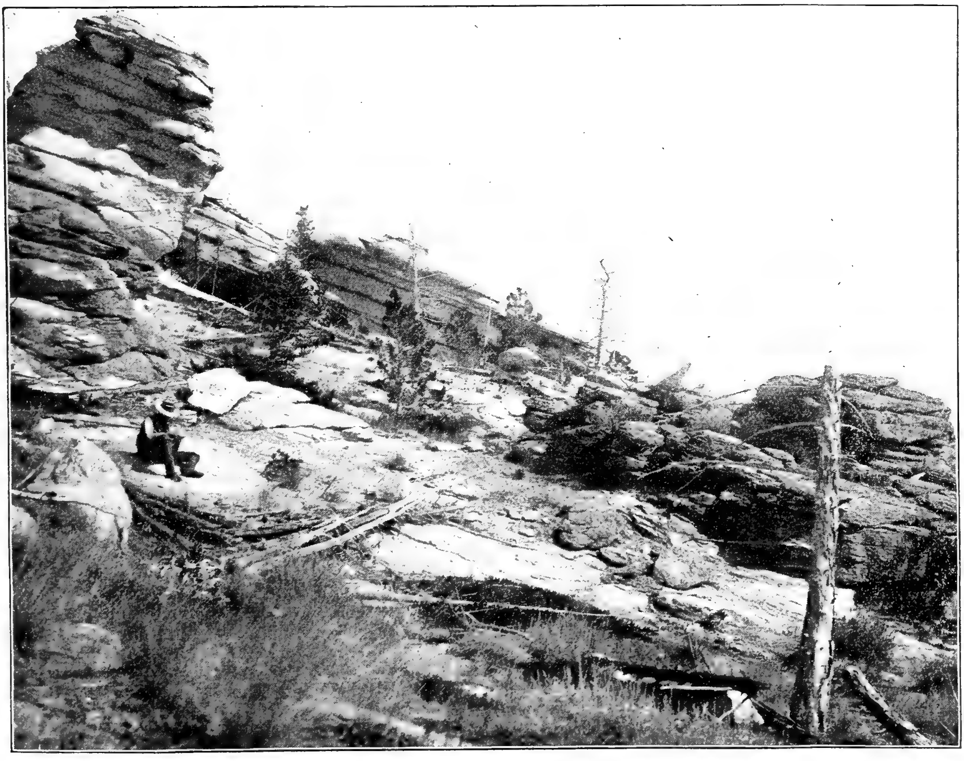

FIGURE 2.—TOP OF THE DARK ZONE.

White syenite above and to the left; to the right below dark shonkinite resting in place on white syenite.

SQUARE BUTTE.

the other, they were not formed by two separate intrusions, but that, on the contrary, they are a geologic unit, and that the mass as a whole was intruded at one and the same time and cooled and crystallized under the same conditions, and that the explanation of the peculiarities which it presents must be sought in another way—one which has an important bearing on theoretic petrology.

As one approaches nearer the top no more black rock is seen; the remainder of the mass is of pure white or pinkish syenite and it presents everywhere the same even grain. The same platy structure continues and at times there are no talus slopes, vegetation, herbage, or even soil, only vast smooth white surfaces of naked rock on whose almost polished slopes it is impossible to climb. Towards the top the average thickness of the plates increases somewhat and their dip gradually becomes less until eventually they are horizontal. It is by their breaking off when horizontal that the enormous ring-shaped, mural precipice which forms the top has been made. The regularity of this platy jointing, together with the even rounding of the corners through weathering where the joint planes cross, gives a most remarkable likeness to colossal masonry in the upper walls. The mural front seen from the plains below has so close a resemblance to bedded and jointed sedimentary strata that only close inspection shows it is not. On the top the slabs produced by jointing are often of great size, forming large tables of stone about 2 feet thick by 15 or 20 feet long and half as broad.

### *ORIGIN OF THE PLATY PARTING.*

From what has been already said in regard to the platy parting which forms so marked a feature of Square butte, it will be seen that it bears the same relation to the mass as a whole as do the enfolding leaves of an onion to the bulb cut in half by a horizontal plane.

We believe that they therefore represent parting surfaces parallel to the former covering of the laccolite from which the isothermal planes of cooling descended into the mass. We can conceive of no other hypothesis which would give a reasonable explanation of their arrangement and disposition, and since Square butte is unquestionably an intrusive mass we regard them as one of the strongest proofs of its laccolitic nature.

Such an arrangement of the parting planes of a cooling igneous mass is by no means unknown, however, as it frequently occurs in the great phonolite domes of central Europe.

### *THE WHITE BAND.*

There still remains an interesting feature of the butte to be described. This is the presence on the south side of a band of white rock which

passes through a number of the dark hoodoos near the lower portion of the dark lower zone. Looking down from the top, it is seen passing through successive hoodoos from right to left on the same horizon, and swinging, perhaps, one quarter of the way around the mountain. Its dip or hade is down and out, similar to that of the platy parting, but at a much more nearly vertical angle, so that the platy parting passes through it (see figure 5). Its shape as a whole, then, is like a segment of the surface of a truncated cone and it enwraps the mountain in a partial way as a bulb is partly enfolded by one of its leaves.

The thickness of the band varies from one to two feet, averaging about 18 inches. Cutting across the dark hoodoos, it forms a striking and con-

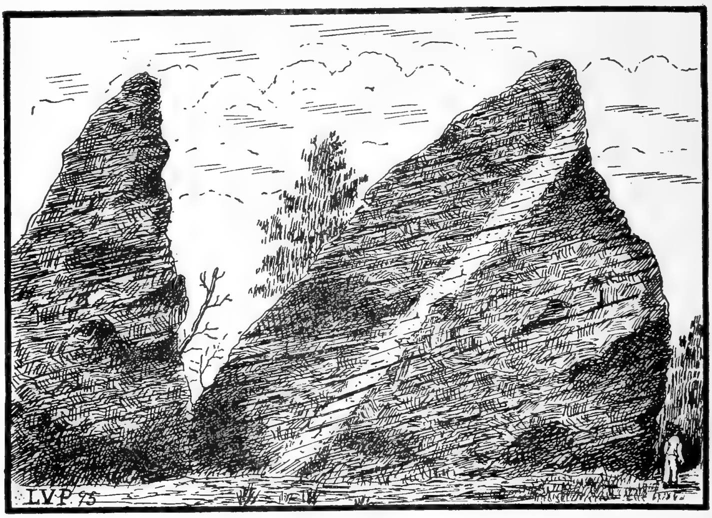


Figure 5.—*The white Band.*

spicuous feature, as may be seen in the sketch shown in figure 5. It was at first supposed to be a dike, but a study of it showed that this is not the case. It was found that there was no sign of contact between it and the dark rock through which it passes. The grain continues all through the same, but at a certain line the augite ceases, the feldspathic constituents increase and make up almost the whole mass of the rock. More convincing yet, as shown in the sketch in figure 5, the platy parting, with the remarkable disk-like structure, passes through both rocks alike, and hence it cannot be a dike, but must be an integral portion of the original liquid mass before it crystallized and cooled. It thus repeats on a smaller scale what has already been observed at the transition zone.

Its petrographic character is similar to the sodalite-syenite described later on.

*DIAGRAMMATIC SECTION OF SQUARE BUTTE.*

The facts which have been detailed in the foregoing pages may now be briefly recapitulated and summarized in the diagrammatic section shown in figure 6.

If we were to pass a vertical axis through the center of the above section and revolve it upon this axis the figure of revolution which would be generated would represent quite correctly the structure of Square butte and the disposition of its several parts. Observe also in this connection the map on page 402.

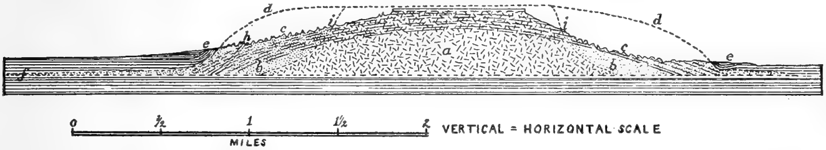


FIGURE 6.—*Cross-section of Square Butte.*

$a$ = white syenite; $b$ = dark basic rock; $c$ = dark hoodoos; $d$ = restored laccolitic cover; $e$ = upturned Cretaceous sandstones; $f$ = protruding sheet or edge of laccolite; $h$ = white band; $i$ = transition zone from white to dark rock, actual and imagined.

*SUMMARY OF FIELD RESULTS.*

From the facts thus shown we believe that Square butte is a laccolite consisting of two kinds of rock, an inner mass of an acid feldspathic variety surrounded by a zone of a basic augitic one. That it is not a case of one intrusion occurring on top of another is clearly shown by the facts already presented, and by the further ones that the relations of the light rock to the dark one are in nowise determined by the varying topography, as must have been the case were the black one a lower intrusive sheet, and by the inclined circular plane of the transition zone, which has approximately the form of the surface of a truncated cone.

Basic peripheral zones in connection with intruded masses of igneous rock, caused by the local concentration of dark colored ferro-magnesian minerals, are known and have been described by several authors, but, so far as we have been able to discover, no example has ever been seen or described before which illustrates them with such striking completeness of process and such perfection of erosive dissection as Square butte.

The significance of the facts and their bearing on theoretic petrology will be discussed in the latter portion of this paper.

*PETROGRAPHY OF SQUARE BUTTE.*

*Characteristics and Minerals of the dark Rock.*—Megascopic and Microscopic.—The dark rock, seen at a distance, appears of a grayish black or

dark stone color, like many basic diorites. In the hand specimen, however, it is found to be so coarse grained that the distinction between the dark colored ferro-magnesian components and the light colored feldspathic ones becomes strongly accentuated, the contrast giving the rock a mottled appearance.

Thus by inspection of the specimen one readily distinguishes the chief components. They are augite in well formed, often rather slender, idiomorphic crystals. of a greenish black color, attaining at times a length of one centimeter, but not averaging perhaps more than a quarter of that length, and biotite, of a bronzy brown color, whose occasional cleavage surfaces attain a breadth of from one to two centimeters, but whose outlines are not clear and idiomorphic, but irreguler, dying away among the other components in shapeless patches. These biotites are, moreover, extremely poikilitic, inclosing the other components. With the lens these broad cleavages are seen to be made up of great numbers of smaller biotite individuals in parallel growths, but including the other minerals. They are thus, as one might say, spongy, skeleton crystals on a large scale.

Filling the interspaces between these dark minerals is a white feldspathic material, from which one obtains occasionally the reflection of a good feldspar cleavage. With the lens one detects greenish grains of olivine in addition.

An inspection of the rock shows at once that its predominant character is the great abundance of the augite, which must form at least one-half of the mass by volume and a greater proportion by weight. With this large amount of augite, it is clear that if it were a dense fine grained rock instead of being so coarse grained as it actually is, a pronounced basaltic appearance would characterize it.

In texture the rock is rather friable and crumbly, and blows of the hammer will frequently cause a specimen to fall into a coarse gravel. This is not due necessarily to alteration, but to the great number of pyroxene prisms and their idiomorphic character, there being little adhesion between their polished faces and the white feldspar material which fills their interspaces. A single heavy blow will often loosen these prisms so that the rock will crumble under the fingers.

In thin-sections under the microscope the following minerals are found to be present: Apatite, iron ore, olivine, biotite, augite, albite, anorthoclase, orthoclase, sodalite, nephelite (?), cancrinite (?) and zeolites.

Apatite.—This is the oldest mineral appearing in idiomorphic outlines even in or abutting into the iron ore. It is in short, stout prisms which often attain a length of 0.5 millimeter. Though commonly colorless, it is at times filled with excessively fine, dusty particles, and then becomes

pleochroic: $\varepsilon$ = pale steel blue; $\omega$ = pale leather brown. This dusty pigment is very apt to be confined to an inner core, which is surrounded by a clear colorless zone. Sometimes the apatites are of a pale red-violet brown and nonpleochroic. The crystals are bounded by the unit prism and several pyramids, but they were too small to determine the planes on material separated by the heavy liquids. The basal parting is common. Cases of twinning like that mentioned by Washington * were not observed. As shown by the analysis, the mineral is present in considerable amount.

Olivine.—This mineral presents the usual type, but is at times of a very pale yellowish color in the section and then shows a faint but clearly perceptible pleochroism in tones of yellow and white. It is generally quite fresh, but sometimes has borders and patches of alteration into a reddish ferruginous material.

Biotite.—The large cleavage surfaces of this mineral, made up of composite individuals, have been described above. It is strongly pleochroic, the colors varying between a very pale brownish orange and a deep umber brown. Cleavage plates appear uniaxial, but in the section, where very thin edges may be found, there is enough of an opening to the arms of the cross in convergent light to establish it as meroxene, the usual variety. The twinning and inclined extinction sometimes seen in the biotites of nephelinite and theralite rocks were not observed.

Besides this brown variety of biotite, there is present also in much smaller amount a pure deep green kind, which, from its method of occurrence, we infer has been formed from the brown one. All gradations are found between them, but in such cases the brown forms an inner core which changes to green on the outer edges. This green kind is particularly to be seen around the olivines, and especially where they come in contact with orthoclase. The appearance of these colorless olivines surrounded by this deep green mantle is very striking. This variety shows very little change of pleochroism or absorption; it is uniaxial, and its double refraction is equally strong with that of the brown. It is quite irregular in outline.

The intermediate position that biotite, in respect to its chemical nature, holds between olivine and feldspar has been noted by Iddings † and is shown in the analysis of its formula. Thus if we consider typical biotite as $(HK)_2 (MgFe)_2 Al_2 Si_3O_{12}$, this separates into $(MgFe)_2 SiO_4 + (HK)_2 O + Al_2O_3 + 2\ SiO_2$, thus furnishing olivine and the oxide molecules necessary for orthoclase. It is possible that this intimate relation may condition the appearance of secondary biotite where olivine and orthoclase are contiguous.

* Jour. Geol. Chicago, vol. iii, 1895, p. 25.

† Origin Igneous Rocks: Bull. Phil. Soc. Washington, vol. xii, 1892, pp. 165, 166.

Pyroxene.—Of all the ferro-magnesian minerals this is by far the most important, determining with the orthoclase the essential character of the rock. Owing to the ease with which it may be detached from the matrix, excellent specimens may be obtained for crystallographic study. In general they present the common form of augite bounded by the planes *a* (100), *b* (010), *m* (110) and *s* ($\bar{1}11$), and somewhat tabular on *a* (100). The form *o* (221) has also been observed. Twinning on *a* (100) occurs, and a crystal of this type having the form *o* ($\bar{2}21$) in addition is shown in figure 7. This crystal was measured on the reflecting goniometer with the following results:

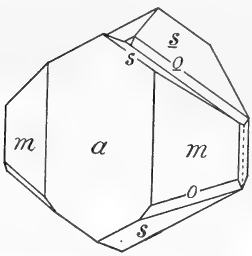

FIGURE 7.—*Twinned Pyroxene Crystal.*

| | Theory. | Measured. |
|---|---|---|
| $a \wedge m$ (100 ∧ 110)...... | 46° 25′ | 46° 27′, 46° 23′, 46° 42, 46° 51′ |
| $s \wedge s$ ($11\bar{1} \wedge 1\bar{1}\bar{1}$)........ | 59 11 | 59 8 |
| $m \wedge o$ ($110 \wedge 22\bar{1}$)...... | 35 29 | 35 40 |
| $s \wedge \bar{s}$ ($11\bar{1} \wedge \bar{1}11$ twin).. | 26 52 | 26 24 26 35 |

The reflections of the signal were only moderately good, and the measured angles are therefore of value only in determining the faces.

As this variety of augite is very common and persistent, not alone at Square butte but generally throughout the Highwood rocks, at times, however, passing into varieties which have a narrow mantle of material rich in the aegirite molecule, as, for example, aegirite-augite, it has been deemed important to investigate it chemically, especially since the Square Butte rock presents such excellent material. The analysis yielded the following results:

*Analysis of Pyroxene.**

| | | Oxygen ratios. | | |
|---|---|---|---|---|
| $SiO_2$.................... | 49.42 | .8236 | .8303 | |
| $TiO_2$.................... | .55 | .0067 | | |
| $Al_2O_3$.................... | 4.28 | .0415 | .0593 | |
| $Fe_2O_3$.................... | 2.86 | .0178 | | |
| FeO.................... | 5.56 | .0772 | | |
| MnO.................... | .10 | .0014 | .4181 | |
| MgO.................... | 13.58 | .3395 | (1.04) | .8176 |
| CaO.................... | 22.35 | .3995 | .3995 | |
| | | | (1.00) | |
| $Na_2O$.................... | 1.04 | .0167 | .0207 | |
| $K_2O$.................... | .38 | .0040 | | |
| $H_2O$ (at 110°).............. | .09 | | | |
| Total.............. | 100.21 | | | |

* By L. V. Pirsson.

In the foregoing analysis the rock was crushed, sifted, and the resulting powder washed and then separated by the use of Retgers'* silver-thallium-nitrate fluid in the apparatus devised by Professor Penfield,† and by this means, aided by the magnet, material of exceptional purity was obtained.

The comparison of the ratios in the analysis shows that CaO to (FeMg)O is as 1 to 1, and that the diopside molecule is thus chiefly present. The presence of the alumina suggests that Tschermak's molecule $\ddot{R}Al_2SiO_6$ must also be present. If we subtract from the sum of the RO molecules enough to make the number of the $R_2O$ equal to that of the $R_2O_3$ and take out the same number of $SiO_2$ molecules, the following table shows the composition of the augite:

$$\left.\begin{array}{l} R_2O = .0207 \\ RO = .0386 \end{array}\right\} .0593 : R_2O_3 = .0593 : SiO_2 = .0593 :: 1 : 1 : 1.$$

$$RO = .7790 : SiO_2 = .7710 :: 1 : 1.01.$$

The very striking agreement of these ratios with the theory must certainly be held to add another very strong proof to the correctness of Tschermak's assumed molecule. The augite then has almost exactly the following composition: $13\ Ca\ (MgFe)\ Si_2O_6 + 2\ (Na_2\ddot{R})\ (AlFe)_2\ SiO_6$.

Since the qualitative analysis of the feldspars has shown the absence of lime, if we deduct enough from the amount found by the mass analysis of the rock to turn the phosphoric anhydride into apatite, a comparison of the remaining amount, 11 per cent, with the 22 per cent of lime demanded by the pyroxene, shows this mineral forms one-half of the rock by weight, a fact which agrees with the appearance of the hand specimen and the study of thin-sections.

Orthoclase.—The predominant feldspar is orthoclase. This is shown by the study of thin-sections, by the separation of the feldspathic constituents by heavy liquids, and may also be inferred from the chemical analysis of the rock where potash is seen to greatly predominate over soda. The mineral is quite fresh and wholly allotriomorphic, its shape being determined by the angular interspaces between the pyroxene in which it is found. Sometimes it assumes rude lath-shaped forms.

It is apt to be filled with fine interpositions whose exact nature cannot be told. They commonly possess the form of their host and their longer axis coincides with that of the crystal, and, so far as can be determined, they are arranged in planes parallel to prism faces. They do not contain bubbles, the reflection band surrounding them is narrow and

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*Jahrbuch für Min. 1893, vol. i, p. 90. This most happy discovery of Professor W. Retgers has placed all working mineralogists and petrographers deeply in his debt.

† We desire to express our thanks to Professor S. L. Penfield for kindly aid in making the separation in apparatus recently devised by him for the special use of the Retgers' fluid, and by means of which the operation may be carried on with nearly the same ease and with all the certainty of the usual heavy liquids.

they do not act on polarized light. From these facts we believe them to be of glass.

Sometimes the orthoclase is colored a pale brownish tone by a fine dusty pigment. It shows in some places a slight tendency to kaolinization and in some others is discolored by the alteration of its interpositions, but usually it is quite fresh. The angle of the optic axes is variable, generally small and sometimes nearly zero.

It sometimes shows intergrown patches of a feldspar which has a higher index of double refraction and is believed to be anorthoclase. In a few cases a tendency for orthoclase laths to group themselves in radial spherulitic forms starting from a common center were observed; since the laths are broad and coarse it does not present a striking feature. Again, in other places the patches of orthoclase filling adjoining areas between augites and olivines have the same optical orientation over some distance, thus presenting a rude poikilitic effect.

Plagioclase.—A triclinic striated feldspar is also present, but in no considerable amount. When the rock powder is placed in the mercuric-iodide solution, and the ferro-magnesian minerals, the magnetite and apatite have fallen out, no feldspathic materials are deposited until a specific gravity of 2.60–2.61 is reached. At this point a very small precipitate is obtained of a feldspar insoluble in HCl. Subjected to qualitative analysis it is found to be free from lime and gives abundant reaction for soda. It is therefore albite, which agrees with the optical character of the mineral in thin-sections, the extinction on either side of the albite twinning plane reaching a maximum of about 15 degrees. The study of this striated feldspar has shown that certain crystals possess remarkable properties. Thus the twinning lamellæ, which are very narrow, can be seen in many cases very distinctly in ordinary light without using the analyzer, some of them possessing a higher refraction than others. Between crossed nicols it is seen that crystals possessing this peculiarity have no position of equal illumination, but the lamellæ can be seen in all positions. It must be, therefore, that these lamellæ possess a different chemical composition from those adjoining them, and since lime is excluded they must represent intergrowths of albite and anorthoclase of varying composition, joined after this singular manner.

Recently Federoff* has called attention to similar intergrowths of twin lamellæ of different composition in the lime-soda feldspars and the same phenomenon had been studied and noted previously by Michel-Levy.†

Nepheline.—The presence of this mineral is only indicated by the fact that the powders falling between the specific gravities of 2.55 and 2.60

* Zeit. fur Kryst: vol. 24, Heft 1 and 2, 1894, p. 130.

† Mineraux des Roches: Paris, 1888, p. 84.

dissolve slightly in HCl, give a small amount of gelatinous silica, with reactions for Na and none for Cl, $H_2O$ or $CO_2$. It must be present in the rock only as a rare accessory mineral, and the recognition in the thin-sections of an occasional patch is rendered difficult by the practically uniaxial character of some of the orthoclase.

Cancrinite.—This is indicated by the fact that the rock powder obtained at a specific gravity of 2.47 dissolved in HCl with gelatinization, and in dissolving slowly and continuously gave off $CO_2$, while carbonates, which would have been thrown down at a higher specific gravity, are absent in the rock, as seen in thin-sections. It can be present only in very small amount, and the certainty of recognizing an occasional piece in the section is diminished by the common occurrence of natrolite. The two minerals are alike in their appearance in fibers with parallel extinction. The cancrinite has, it is true, a higher double refraction, but sections may be as low as natrolite, and only by establishing the uniaxial character can the cancrinite be definitely determined. This we have not been able to do, and its presence is therefore only inferential.

Sodalite.—This also occurs as an accessory component. The rock powder separated below a specific gravity of 2.40 consists partly of this mineral, together with some zeolites. It dissolves readily in HCl and $HNO_3$, the solution in the latter yielding a precipitate with $AgNO_3$ and none with $BaCl_2$, thus showing the presence of sodalite and absence of hauyn or nosean. In thin-section it is very clear and limpid, but contains little interpositions somewhat like the feldspars. The actual amount of sodalite in the rock is very small, and this is shown also by the small amount of chlorine obtained in the analysis, part of which belongs to the apatite present.

Natrolite.—The presence of zeolites is indicated by the water obtained in the analysis. Some analcite may occur, but the chief zeolite is natrolite, which is present in considerable amount. It is recognized by its parallel extinction and positive character, by the small angle of the optic axes, and by the strength of its double refraction, which compared with the feldspars, rises to .010–.012. It occurs in characteristic bundles of fibers, and is in part secondary after sodalite and in part after albite and anorthoclase. The fibers are plainly seen eating their way into the feldspar, and in a given crystal they do this according to a definite oriented direction, as the different patches in the crystal always have the same orientation.

Chemical Composition.—The chemical composition of the rock is shown in the following analysis. In it the minute trace of $CO_2$ due to a little possible cancrinite is not determined, nor is the amount of rarer

elements which could not influence its results. The very large amount of $P_2O_5$ is noticeable, and proves what the microscope reveals, the large amount of apatite present. The amount was fixed by two closely agreeing determinations.

*Analysis of Shonkinite.**

| | |
|---|---|
| $SiO_2$ | 46.73 |
| $TiO_2$ | .78 |
| $Al_2O_3$ | 10.05 |
| $Fe_2O_3$ | 3.53 |
| FeO | 8.20 |
| MnO | .28 |
| MgO | 9.68 |
| CaO | 13.22 |
| $Na_2O$ | 1.81 |
| $K_2O$ | 3.76 |
| $H_2O$ | 1.24 |
| $P_2O_5$ | 1.51 |
| Cl | .18 |
| | 100.97 |
| O=Cl | .04 |
| Total | 100.93 |

To be noted here is the low silica and very high magnesia, iron and lime. It is evident that although the feldspar raises the silica percentage it is not in sufficient amount to counteract the olivine, iron ore, biotite, apatite and other minerals which tend to lower it. The water comes in part from zeolites.

Structure and Classification.—The minerals in the order of their crystallization are, first, apatite, then iron ore, olivine, biotite and augite. The period of the last two overlaps. Then followed the feldspathic components, whose succession is quite doubtful as regarding one another, except that on the whole the albite-anorthoclase group appears to be among the earliest.

These minerals lie unoriented, forming a holocrystalline, rather coarse granular hypidiomorpic structure. It resembles in many respects the coarser grained theralites of the Crazy mountains; in others certain coarse-grained dolerites. The structure is illustrated on the next page by figure 8, which indicates also the prominent position the augite plays in the composition of the rock.

From what has been given in the foregoing description it is evident

* By L. V. Pirsson.

that in this dark rock of Square butte we have a granular, plutonic rock, composed essentially of *augite* and orthoclase, with smaller amounts of olivine and iron ore and with accessory apatite, sodalite, nepheline, etcetera. In its chemical composition it stands very close to certain vogesites and minettes—basic rocks of the syenitic group. It differs from them essentially, first, in its mineral composition and, second, in its structure. For a rock of its character there seems to be no position in any of our present schemes of classification. It would be manifestly improper to term such a rock an augite-syenite, as its chemical composition removes it very far from syenites. It bears indeed such a relation to augite-syenite as vogesite does to hornblende-syenite; that minette or, perhaps better, the Durbachite of Sauer * does to mica-syenite.

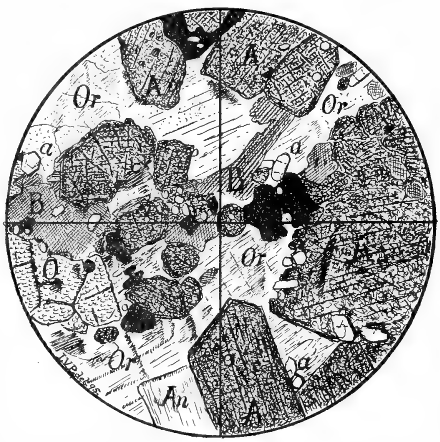

FIGURE 8.—*Micro-drawing of Shonkinite multiplied* 14 *Diameters.*

*A* = augite; *O* = olivine; *B* = biotite; *Or* = orthoclase; *An* = anorthoclase; *A* = apatite. Actual field, 4 mm.

It stands generally related indeed to rocks of the basic class—low in $SiO_2$, high in MgO, CaO and FeO, and thereby related to rocks of the lamprophyre family. Moreover, this type is found in the Highwoods not only in the outer mantle of Square butte, although constituting there an immense mass, but at many other points forming great intrusive stocks. As briefly noted by Lindgren,† the variability of the augite and orthoclase in the Highwood rocks is very great. As in the gabbro family we have every range from anorthosite at one end to peridotites at the other, with the gabbros standing in an intermediate position, so in the Highwoods variation extends from syenites practically devoid of ferro-magnesian minerals to those in which augite becomes the chief constituent, though the basic extreme entirely devoid of feldspar has not been observed by us.

Name Shonkinite.—For this type of rock, then, we propose the name of shonkinite, from shonkin, the Indian name of the Highwood range, by which name, indeed, it is still called by many, and shonkinite we define as a granular plutonic rock consisting of essential augite and orthoclase,

* Mitt. d. Bad. geol. Landesanstalt, ii Bd., p. 247.

† Proc. California Acad. Sci., ser. 2, vol. iii, p. 47. Tenth Census, vol. xv, p. 725.

and thereby related to the syenite family. It may be with or without olivine, and accessory nepheline, sodalite, etcetera, may be present in small quantities. The Square butte rock is thus olivine-shonkinite, with these accessory minerals.

The fine grained dense porphyritic forms which bear the same relation to shonkinite that trachyte does to syenite are dark to black heavy basalts. They are, in fact, orthoclase basalts, a type which although so far as we know has not yet been described from European localities, is by no means rare in western America. Besides its occurrence in the Highwoods, and also in other localities in Montana alluded to by Lindgren,* its presence in the Absaroka range and Yellowstone National Park has been mentioned by Iddings.† Somewhat similar rocks have been also mentioned by Zirkel,‡ who does not, however, discuss this type of basalts in the recent edition of his great work on petrography, so far as we have been able to discover in the absence of complete indexing.

*White Rock or Sodalite-syenite.*—The petrography of the light colored inner core of the denuded laccolite has been so completely investigated by Lindgren and Melville § that a further examination enables us to add but very little to their comprehensive description. The rock is shown to be a sodalite-syenite, and for purposes of convenience we briefly summarize their results, referring to the original paper for fuller information.

Megascopically the rock when very fresh is nearly pure white, often with a brownish to pinkish tinge, consisting mainly of feldspar, which often reaches 5 millimeters in diameter. Through this are scattered slender, glittering black hornblende prisms which attain at times the same length. It is scarcely sufficient in amount to detract at a distance from the general whiteness of the rock. Small grains of a salmon to brown colored sodalite are also present. The rock is thus rather coarsely granular, and in fact of the same size grain as the shonkinite, with which it is so intimately connected.

The microscope shows the following minerals present in the order of their formation: Apatite, hornblende, orthoclase (with some albite), sodalite and analcite. The hornblende is in slender prisms bounded by *m*, 110 and *b*, 010, terminations wanting, frequently twinned on *a* (100). It is strongly pleochroic $\mathfrak{c}$ and $\mathfrak{b}$, deep brown $\mathfrak{a}$, yellowish brown and absorption very great $\mathfrak{b} = \mathfrak{c} > \mathfrak{a}$. An outer mantle often shows a greenish color (from change into the arfvedsonite molecule?—L. V. P.). Angle $c \wedge \mathfrak{c} = 13$ degrees; is idiomorphic against the feldspathic constituents.

* Loc. cit., p. 50; also, Am. Jour. Sci., vol. 45, 1893, p. 289.
† Bull. Phil. Soc. Washington, vol. 12, 1892, p. 169.
‡ Mic. Petrog. Fortieth Par., 1876, p. 225.
§ Loc. cit.

It is closely related to barkevikite, as shown by the analysis quoted later in this article.

The orthoclase occurs in lath-shaped forms and in irregular grains. Those abutting against sodalite show crystal faces. Associated with the orthoclase is a triclinic feldspar referred to albite. The sodalite is found in irregular grains between the feldspars, allotriomorphic in regard to them, idiomorphic against analcite. The latter, which is in considerable amount, was along with the sodalite separated and analyzed. The analcite is thought to be derived from the albite. The rock is calculated from the analysis (given later in this paper) to consist of 66 parts of feldspar, 23 of hornblende, 8 of sodalite and 3 of analcite.

In addition to these facts we have only to add that in the additional material studied by us we have detected a small amount of nephelite, which is being changed by borders, bays and tongues of analcite eating into it and thus suggesting an additional origin for the analcite; also considerable natrolite is sometimes present. Its fibrous masses are secondary after sodalite and at times it completely replaces it.

### *GENERAL PETROLOGY OF SQUARE BUTTE.*

The facts which have already been given in regard to Square butte show it to be one of the most remarkable and interesting occurrences of an igneous rock that has been described and from a petrologic point of view one of the most important; for while the differentiation of a molten magma as a factor in the formation of igneous rocks is now regarded by the majority of petrologists as an established fact, it is also true that the theory has been founded almost entirely upon inferential proof and by the exclusion of other hypotheses. The direct proofs which have come under observation have not been all that could be desired, and some of them indeed, as in the case of mixed dikes, have had more than one interpretation.

In the case of Square butte, however, the proof of differentiation is unequivocal and direct, for in no other rational way, we believe, would it be possible to explain the disposition of the rock masses, the cone-in-cone arrangement of the two differing masses of intruded igneous rock, so unlike in chemical and mineral composition, yet geologically a unit and absolutely homogeneous in granularity and texture and so perfect in continuity of structure and platy parting.

It is therefore a matter of interest to compare the chemical and mineral composition of these two rocks, the syenite and shonkinite, with one another and see, so far as possible, how and under what conditions the differentiation has taken place. For this purpose the analyses of the two rocks are here compared:

| | Rock analyses. A | B |
|---|---|---|
| $SiO_2$ | 56.45 | 46.73 |
| $TiO_2$ | .29 | .78 |
| $Al_2O_3$ | 20.08 | 10.05 |
| $Fe_2O_3$ | 1.31 | 3.53 |
| FeO | 4.39 | 8.20 |
| MnO | .09 | .28 |
| MgO | .63 | 9.68 |
| CaO | 2.14 | 13.22 |
| $Na_2O$ | 5.61 | 1.81 |
| $K_2O$ | 7.13 | 3.76 |
| $H_2O$ | 1.77 | 1.24 |
| $P_2O_5$ | .13 | 1.51 |
| Cl | .43 | .18 |
| | 100.45 | 100.97 |
| O = Cl | .10 | .04 |
| Total | 100.35 | 100.93 |

| | Chief oxides to 100. $A^1$ | $B^1$ | Molecules. $A^2$ | $B^2$ |
|---|---|---|---|---|
| $SiO_2$ | 57.83 | 48.36 | 65.61 | 49.27 |
| $Al_2O_3$ | 20.57 | 10.40 | 13.62 | 6.27 |
| FeO | 5.72 | 11.78 | 5.39 | 10.02 |
| MgO | .64 | 10.01 | 1.10 | 15.28 |
| CaO | 2.19 | 13.68 | 2.65 | 14.84 |
| $Na_2O$ | 5.75 | 1.88 | 6.33 | 1.82 |
| $K_2O$ | 7.30 | 3.89 | 5.30 | 2.50 |
| | 100.00 | 100.00 | 100.00 | 100.00 |

In the above table the analysis of the syenite by Melville is given under A; that of the shonkinite by Pirsson is repeated under B. For purposes of more easy comparison they are repeated under $A^1$ and $B^1$, with the non-essential elements omitted, the ferric iron reduced to ferrous, and the whole brought to 100. This at once brings out the most important chemical characteristics of the shonkinite. its very high iron, lime and magnesia, properties which show its difference from the typical syenites and its approach to the basaltic and lamprophyre groups. In $A^2$ and $B^2$ are given the percentages of molecules in the rocks derived from the oxygen ratios. The percentages by molecules gives in general a much clearer idea of the chemical composition of a rock than that by weight, because it shows more correctly its capacity for forming minerals.

From the above table it is seen at once that the magnesia shows the greatest differentiation, then the lime, and then iron. The relative proportion of the alkalies to each other and to alumina is about the same in each; they vary some, it is true, but the variation is insignificant compared with that of the bivalent oxides. The tendency of variation, then, has been for the lime, iron and magnesia molecules toward the outer cooling surface, while the alkalies and alumina have remained a constant, or if we imagine the silica to remain a constant, they have moved inwardly. It is also clear that the bivalent oxides have not kept a nearly constant ratio, for magnesia is much more concentrated than iron.

Of course, this implies that the molten mass before intrusion into the laccolite cavity was of uniform composition; that one liquid mass of one kind was not succeeded by another of different composition. The

very regular and symmetric arrangements of the parts, the absence of all inclusions or "schlieren," the cleanness of the zonal edge, together with the common properties already pointed out, utterly preclude this idea. There are, indeed, places in the Highwoods where intruded masses show further movements after differentiation has taken place, with the result of remarkably banded and streaked rocks, whose very occurrence shows that such was not the case at Square butte.

We are, indeed, forced to conclude at every step that the mass was originally homogeneous, and that differentiation took place by the diffusion of the bivalent oxides toward the outer surfaces.

It would add greatly to the value of the results here presented if we could know or could obtain the composition of the original magma in which the differentiation took place. This, however, cannot be done by comparing the masses of the two rocks, because, although it is probable that the amount of syenite now present represents pretty nearly the original one—that is, that there has been only a small erosion of that rock—the case is quite different with the shonkinite, a very large part of which has been carried away; hence, not knowing the relation of the two masses involved, we cannot estimate the composition of the original magma. It is evident, however, that it must have been between the syenite and shonkinite.

Shonkinite, however, occurs in large bodies in the neighborhood of Square butte and elsewhere throughout the Highwood range, while rocks closely related to it in chemical and mineral composition are found in the form of dikes, extruded lavas and breccias. Throughout the district what may be called acid or highly feldspathic rocks play but a subordinate rôle. In view of these facts, we are inclined to believe that the composition of the original magma approximated more closely to shonkinite than to the syenite.

It will be seen, therefore, that Square butte presents in a demonstrative way the same idea that Brögger inferentially deduced and presented as the explanation of the processes of differentiation by which the varied rocks of the region of south Norway have been formed.*

Recently Harker† has described an interesting occurrence of a gabbro massif, which grows steadily more basic or richer in the ferro-magnesian minerals as the outer boundary is approached. Harker explains this occurrence by pointing out that the order of concentration of the minerals is the same as the order of their crystallization, and hence accounts for the differentiation as a process of crystallization. Square butte is also more basic as we approach the outer boundary, but the transition occurs abruptly, so to speak, or within such a narrow zone that it practically

* Zeit. für Kryst., vol. xvi, 1890, p. 85.

† Quart. Jour. Geol. Soc., vol. l, 1894, p. 311.

does. It is evident, however, that differentiation did not take place at Square butte as a process of crystallization, but in a liquid magma before any crystallization occurred. This is rendered quite evident, since none of the ferro-magnesian minerals of the shonkinite are found in the syenite. The only one, indeed, which is found in the syenite is the barkevikite-like hornblende, while in the shonkinite are found iron ore, biotite, olivine and pyroxene. Thus Square butte affords a striking confirmation of the ideas recently expressed by Brögger in his remarkable work on the basic rocks of Gran.*

It is a matter of some interest here to compare the composition of the augite of the shonkinite, by far its most prominent constituent, and the hornblende of the syenite from Melville's analysis.

| | Barkevikite. | Augite. |
|---|---|---|
| $SiO_2$ | 38.41 | 49.42 |
| $TiO_2$ | 1.26 | .55 |
| $Al_2O_3$ | 16.39 | 4.28 |
| $Fe_2O_3$ | 3.75 | 2.86 |
| FeO | 21.75 | 5.56 |
| MnO | .15 | .10 |
| MgO | 2.54 | 13.58 |
| CaO | 10.52 | 22.35 |
| $Na_2O$ | 2.95 | 1.04 |
| $K_2O$ | 1.95 | .38 |
| $H_2O$ | .24 | .09 |
| | 99.91 | 100.21 |

The result of the increase of magnesia and lime shows itself in the change in composition of the dark mineral. The iron shows a movement in the opposite direction; in the syenite it is all found in the hornblende; in the shonkinite large quantities had been used for the iron ore and olivine, and to some extent for the biotite before the augite began crystallizing; hence it is not so prominent as in the barkevikite.

In general, however, the difference is of like kind with that shown by the mass analyses of the rocks and shows clearly how the composition of the prominent dark mineral is a function of the magma in which it is formed. That minerals indeed are so often conditioned by the magma in which they are formed is without doubt the fact that has given to some the idea that definite mineral molecules individualized as such can exist in the molten magma.

Recently Johnston-Lavis † has formulated a theory for the different composition of igneous rocks occurring at the same eruptive center by supposing that the body of molten magma which gave them birth was

* Quart. Jour. Geol. Soc., vol. l, 1894, p. 15.
† Natural Science, vol. iv, February, 1894.

originally homogeneous, but became of different composition on its outer margin by fusion and absorption of the country rocks with which it came in contact.

Whether this is ever so or not is fairly a matter for argument. That such a process cannot, however, be appealed to as a general explanation is clearly shown at Square butte, where the outer margin, as already shown, is much more basic than the interior, and yet the magma has been intruded into sandstones—that is, rocks much more acid than the original magma.

The singular white band which has been previously described as occurring on the south side of Square butte presents on a small scale the same process of differentiation between the syenite and shonkinite. We believe that it represents what may be called a residual differentiation—that is, that after the main process had already taken place and the outer margins of the laccolitic cavity were filled with that magma which was later going to cool and crystallize into shonkinite this further differentiation took place in the shonkinite fluid.

The latter, probably owing to increasing viscosity, was not able to permit the white band fluid to pass in by diffusion to the main body of the syenite and it therefore remained parallel to the transition zone of the two principal masses.

It will be noticed that a section passing from the center to the south of Square butte passes twice through white feldspathic and twice through dark augitic rock, if we take the white band into consideration. Further, that these various layers have a concentric arrangement with respect to each other, and hence one sees that Square butte presents on a huge scale a rude parallel to those spheroidal masses which sometimes occur in granites and diorites, and which are often remarkable for the regular concentric arrangement of spherical shells of varying composition.

Bäckström * has sought to explain certain cases of such spheroidal masses as portions of a partial magma separated out in the liquid state from a mother liquor, in which, by sinking temperature, they are no longer soluble.

Bäckström has expanded this idea and sought a general explanation † for the differentiation of igneous magmas in a process of "liquation," by which is meant that an originally homogeneous magma by sinking temperature becomes unstable and separates into two or more fluids which are insoluble in each other—that is, non-miscible. It seems to us that the concentric arrangement of parts and the clear and sharp line of division between them at Square butte point very favorably to this view as

* Geol. Foren. Förh., Stockholm, Bd. 16, 1894, p. 128.
† Jour. of Geol., Chicago, vol. i, 1893, p. 773.

an explanation. Bäckström, however, expresses himself as strongly against the idea of "diffusion," by which we suppose is meant the diffusion of the basic oxides toward the outer cooling surfaces. That such diffusion, however, can take place is clearly shown at Square butte, where it has. In any case a diffusion of some kind must take place or the magma would remain homogeneous. We do not see indeed that Bäckström has advanced any reason which would prove that these two ideas, diffusion and liquation, necessarily exclude each other. We do not see in fact why both may not be operative.

As a matter of fact, the more that the differentiation of igneous rocks is studied the more evident it becomes that no one simple process will explain all cases, but that to produce such results a variety of factors must be included, any one or all of which may operate to produce a given phenomenon. Such, for example, may be pressure, change of temperature, convection currents (which are shown by the "flow structure" and parallel arrangements of phenocrysts on the margins of intruded masses), diffusion of certain oxide molecules toward cooling surfaces, liquation and crystallization. The operation of these on molten silicate magmas is as yet but little understood and much more must be done and learned before any generally satisfactory theory for differentiation can be advanced.

Whatever may have been the causes at work at Square butte, two things at least are evident, that the basic oxides concentrated toward the outer edges and that the changes which produced this took place very slowly and with extreme regularity, allowing the differentiation to be very complete and thorough.

### *SUMMARY.*

Square butte is a laccolite which has been intruded in Cretaceous sandstones. After the intrusion differentiation took place in the liquid mass, the iron, magnesian and lime molecules being greatly concentrated in a broad exterior zone, leaving an inner kernel of material richer in alumina, alkalies, and silica. This crystallized into a sodalite-syenite, while the outer mass formed a basic granular rock composed essentially of augite and orthoclase, to which the name of shonkinite has been given. After solidification the cooling developed a fine platy structure throughout the mass parallel to the form of the laccolitic cover. Since then erosion has removed the cover, laying bare the laccolite and dissecting it so that its structure is clearly brought out.

Owing to the erosion and the platy parting the broad marginal zone of shonkinite has been carved into a wide band of singular monoliths which extends around the mountain on its lower slopes.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 6, PP. 423-528, PL. 27 APRIL 27, 1895

# PROCEEDINGS OF THE SEVENTH ANNUAL MEETING, HELD AT BALTIMORE, DECEMBER 27, 28 AND 29, 1894

HERMAN LEROY FAIRCHILD, *Secretary*

## CONTENTS

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## Session of Thursday, December 27

The Society was called to order by the President, Professor T. C. Chamberlin, at 10 o'clock a m, in the geological laboratory of Johns Hopkins University, in which room all the sessions of the meeting were held. The President introduced Dr Daniel C. Gilman, the President of the University, who welcomed the Society in a cordial and graceful address, referring particularly to the geological equipment of the University and the recent opening of the building devoted wholly to geological science, in which this meeting was held, the occasion being in a sense an auspicious dedication of the building. He spoke with feeling of the loss to geology, the University and the Society by the death of Professor George H. Williams. President Chamberlin responded in a few words of thanks to President Gilman and the University.

The report of the Council was called as the first item of business and was submitted by the Secretary in print and distributed to the Fellows.

### *REPORT OF THE COUNCIL*

*To the Geological Society of America,*
*in Seventh Annual Meeting assembled:*

With this meeting begins the seventh year in the life of the Society. The Council congratulates the Fellows upon the eminent success it has achieved, and rejoices with them in the outlook for future prosperity and usefulness. The influence of the Society has been marked in the direction of more sympathetic coöperation and harmonious working among the geologists of the continent. Twelve meetings have been held, and the social profit of those gatherings has been even greater, perhaps, than the scientific. The five handsome volumes of the Bulletin are evidence of a working Fellowship and an active organization. Notwithstanding the great cost of the Bulletin and the expenses of administration, due

to a scattered membership, it has been possible thus far, by careful management and economy, to carry on the publication without abridgment. It has, however, been necessary to make a choice from the material offered for publication, and it will probably be necessary to make even more strict selection in the future. To the officers upon whom has fallen the burden of administration the success of the Society has been a great satisfaction.

During the past year the Council has held two well attended meetings, in conjunction with the Boston and Brooklyn meetings of the Society, each consisting of several sessions. The details of the administration are shown in the following reports of the officers:

### Secretary's Report

*To the Council of the Geological Society of America:*

*Membership.*—For the second time the Society has lost an officer by death. Second Vice-President George H. Williams died on July 12. Mr Amos Bowman died June 18.

The last printed roll of membership bears the names of 220 living and nine deceased Fellows. At the Brooklyn meeting eleven persons were elected, and all have qualified, as follows: Miss Florence Bascom, R. C. Hills, E. D. Ingall, R. T. Jackson, D. F. Lincoln, C. J. Norwood, C. Palache, L. V. Pirsson, H. L. Smyth, L. G. Westgate, W. S. Yeates. Five Fellows have been dropped from the roll for non-payment of dues and seven others are now so in arrears that they are liable to be dropped. Five candidates for membership are now before the Society.

The Fellowship of the Society is at this date distributed over the continent as follows: District of Columbia, 34; New York, 27; Canada, 23; Pennsylvania, 17; Massachusetts, 17; California, 12; Ohio, 12; Illinois, 10; Connecticut, 7; Iowa, 7; Minnesota, 6; Michigan, 5; New Jersey, 5; Kentucky, 4; Missouri, 4; Alabama, Colorado, Kansas, Texas, Virginia, Wisconsin, 3 each; Maryland, South Dakota, Vermont, West Virginia, 2 each; Arizona, Georgia, Idaho, Indiana, Maine, Mississippi, North Carolina, New Hampshire, Rhode Island, Tennessee, 1 each, and 1 each in Brazil, Burma and Mexico. Total, 229.

*Distribution of Bulletin.*—The Secretary calls attention to the matter under this head in his report of last year (volume 5, page 610), which need not be repeated here, except to state that the edition of volume 1 was only 500 copies, and that the first two volumes were distributed to the Fellows direct from the printers. A comparison of the following report with last year's report will give the details for the past year:

DISTRIBUTION OF BULLETIN FROM THE SECRETARY'S OFFICE DURING 1891–1894

*Complete Volumes*

| | Vol. 1. | Vol. 2. | Vol. 3. | Vol. 4. | Vol. 5. |
|---|---|---|---|---|---|
| In reserve | 80 | 325 | 369 (?) | 373 (?) | 362 |
| Donated to institutions ("exchanges") | 84 | 84 | 83 | 83 | 83 |
| Held for "exchanges" | 9 | 9 | 10 | 10 | 10 |
| Sold to libraries | 67 | 68 | 66 | 63 | 61 |
| Sold to Fellows | 16 | 13 | 7 | 3 | 2 |
| Sent to Fellows to supply deficiencies | 2 | 1 | 1 | .... | .... |
| Donated | 4 | 4 | 3 | 2 | .... |
| Bound for office use | 2 | 2 | 2 | 2 | 2 |
| Distributed to Fellows in brochures as issued | ... | .... | 209 | 214 | 214 |
| Number of complete copies received | 264 | 506 | 750 (?) | 750 (?) | 734 |

*Brochures*

| | Vol. 1. | Vol. 2. | Vol. 3. | Vol. 4. | Vol. 5. |
|---|---|---|---|---|---|
| Sent to Fellows to supply deficiencies | 45 | 121 | 39 | 41 | 18 |
| Sent to libraries to supply deficiencies | ... | 7 | 4 | 3 | .... |
| Sold to Fellows | 6 | 10 | 2 | 4 | 3 |
| Sold to the public | 10 | 8 | 5 | 7 | 4 |
| Donated | 3 | 3 | 3 | 3 | 1 |

For the sake of economy and to prevent the accumulation of a large and possibly useless reserve of the Bulletin the edition of volume 6 has been reduced to 500 copies.

*Subscriptions.*—The number of regular subscribers to the Bulletin is 53; of whom 21 receive the brochures and 32 the completed volumes. The special orders for published volumes are included in the following table.

*Bulletin Sales.*—The receipts from the sale of the Bulletin during the year amount to $520.85. The money is deposited with the Security Trust Company, subject to the check of the Treasurer, and draws 4 per cent interest.

RECEIPTS FROM SALE OF BULLETIN DURING 1894

*By Sale of Complete Volumes*

| | Vol. 1. | Vol. 2. | Vol. 3. | Vol. 4. | Vol. 5. | Total. |
|---|---|---|---|---|---|---|
| From Fellows | $13 50 | $13 50 | $12 00 | $10 50 | $8 00 | $57 50 |
| From libraries | 25 00 | 25 00 | 35 00 | 100 00 | 275 00 | 460 00 |
| Total for 1894 | 38 50 | 38 50 | 47 00 | 110 50 | 283 00 | 517 50 |
| By last report (1893) | 349 10 | 346 00 | 308 50 | 210 00 | 15 00 | 1,228 60 |
| Total to date | $387 60 | $384 50 | $355 50 | $320 50 | $298 00 | $1,746 10 |

*By Sale of Brochures*

| | Vol. 1. | Vol. 2. | Vol. 3. | Vol. 4. | Vol. 5. | Total. | |
|---|---|---|---|---|---|---|---|
| From Fellows....... | .... | $0 95 | $0 30 | $0 15 | $0 15 | $1 55 | |
| From the public..... | $5 80 | .... | .... | .... | 1 00 | 6 80 | |
| Total for 1894... | 5 80 | 0 95 | 0 30 | 0 15 | 1 15 | 8 35 | |
| By last report (1893). | 12 25 | 12 05 | 3 70 | 4 70 | .... | 32 70 | |
| Total to date.... | $18 05 | $13 00 | $4 00 | $4 85 | $1 15 | | $41 05 |

| | |
|---|---|
| Grand total........................................... | $1,787 15 |
| Received for volume 6, in advance.......................... | 35 00 |
| Total receipts to date ....................................... | $1,822 15 |
| Amount charged and uncollected ............................ | 60 20 |
| Total Bulletin sales to date................................ | $1,882 35 |

*Exchanges.*—The list of institutions to which the Bulletin is donated now numbers 83. The distribution by countries is given in the last report, excepting two additions—one to Italy and one to Australia. This list will soon be published in connection with the list of the library.

*Library.*—Except the request for personal and historical matter sent out by Professor Hitchcock, no effort has been made to gather library material, but through the distribution of the Bulletin the Society has received a considerable amount of geologic and other scientific literature. The proper disposition of this matter soon became the subject of consideration by the Council. It was found that the Society could have this material cared for and made available to the Fellows and to the public without expense to the Society. At the Washington Summer Meeting a committee was appointed, consisting of the Secretary, Dr I. C. White and Professor T. C. Chamberlin, to select the depository and make the contract. Under reports of progress the committee has been continued, with replacement for a time of Professor Chamberlin by Professor J. J. Stevenson. The negotiation has been conducted with deliberation and with regard to the Society's interest, and a contract has recently been closed with the Case Library of Cleveland. This statement is made in advance of the formal report of the committee in order to bring it at once before the Society.

By the contract with the Case Library the Society, while retaining ownership of the material, is relieved of all expense, with the privilege of removal upon one year's notice by repayment of part of the expenditure for binding. Should the Society remove its library only to take it under its own care, the amount of money to be refunded on account of binding would be small, or perhaps nothing, if several years elapse before removal.

At this writing the books are still in the hands of the Secretary. A

list of "accessions" has been prepared and the volumes numbered accordingly. It is recommended that this list, which is appended,* should be printed and distributed to the Fellows. It was not practicable in this list to attempt to give the contents of volumes or the titles of included papers, but in future lists of accessions such contents and titles should be given.

The Secretary suggests that the library be made immediately available to the Society under rules somewhat as follows:

1. That Fellows be permitted to draw out material in reasonable quantity for a period not exceeding two months.

2. That the transportation charges both ways and other expenses be paid by the Fellow so borrowing.

3. That the Fellow be held responsible only for such loss or damage as may occur through his fault, as, for example, by insufficient wrapping or misdirections.

EXPENDITURE OF SECRETARY'S OFFICE FOR THE SOCIETY'S FISCAL YEAR, NOVEMBER 30, 1893, TO NOVEMBER 30, 1894

*Account of Administration*

| | | |
|---|---|---|
| Postage | $40 18 | |
| Telegrams | 1 66 | |
| Expressage | 4 94 | |
| Stationery and records | 8 44 | |
| Printing, including stationery | 156 93 | |
| Meetings | 2 00 | |
| Library | 14 96 | |
| Total | | $229 11 |

*Account of Bulletin*

| | | |
|---|---|---|
| Postage | $100 50 | |
| Telegrams | 70 | |
| Expressage | 68 66 | |
| Wrapping | 1 90 | |
| Printing | 13 75 | |
| Binding | 2 50 | |
| Collection of checks | 2 25 | |
| Labor, correction in volume 5 | 14 00 | |
| Total | | $204 26 |
| Total expenditure | | $433 37 |

All of which is respectfully submitted.

H. L. FAIRCHILD,
*Secretary.*

ROCHESTER, NEW YORK, *December 21, 1894.*

* This list is printed as the closing matter of this volume.

## Treasurer's Report

*To the Council of the Geological Society of America:*

In accordance with the By-Laws, a condensed statement of the operations of the Treasury for the year ending November 30, 1894, is hereby submitted:

RECEIPTS

| | | | |
|---|---|---|---|
| Balance in Treasury November 30, 1893 | | $633 09 | |
| 188 Fellowship fees | | 1,880 00 | |
| 15 initiation fees | | 150 00 | |
| 1 life commutation fee | | 100 00 | |
| Interest on investments | | 158 96 | |
| Sales of publications | | 576 80 | |
| Assessments on cost of publications | | 10 00 | |
| | | | $3,508 85 |

DISBURSEMENTS

| | | | |
|---|---|---|---|
| Expenses of Secretary's office: | | | |
| On account of administration | $403 19 | | |
| On account of Bulletin | 219 06 | | |
| | | $622 25 | |
| Expenses of Editor's office | | 174 00 | |
| Printing account, circulars, etcetera, Rochester | | 166 33 | |
| Bulletin publication: | | | |
| Printing account | | 1,792 86 | |
| Engraving account | | 175 65 | |
| Photograph account | | 14 80 | |
| Investment account | | 100 00 | |
| | | | $3,045 89 |
| Balance in Treasury November 30, 1894 | | | $462 96 |

The invested funds stand the same as in the last report.

Respectfully submitted.

I. C. White,
*Treasurer.*

## Editor's Report

*To the Council of the Geological Society of America:*

Since the presentation of the Editor's last report volume 5 has been published and some progress made upon the printing of volume 6. In number of pages volume 5 outranks any Bulletin yet published by the Society, while in illustrative material it is surpassed only by volume 2. The career of volume 5 is instructive in that it shows the possibility of giving to the members promptly the papers accepted for publication. All of the Madison material placed in the Editor's hands was printed and distributed before the close of November, 1893, while the last brochure of the volume—"Proceedings of the Boston meeting"—went to

press April 30; that is, 595 pages were printed and distributed between that date and the previous January first. It is to be regretted that equal promptness cannot be recorded as to volume 6. This is due solely to the slowness of some of the authors in forwarding their papers to the Publication Committee. The Proceedings brochure and six other manuscripts were approved by the committee, and while all are at this date in the hands of the printer and 102 pages (more than were in type at the same time last year) have already been printed, still all might have been distributed long ago, for there have been weeks at a time when both Editor and printer were without copy. It is true this tardiness affects only the individual author so long as it does not interfere with, by overlapping upon, the manuscripts accepted at the following meeting. When this happens, as now will be the case, it imposes a hardship to which other publishing members and the Society in general should not be subjected.

Last year the Editor felt it to be his duty to take exception to the condition of manuscripts presented for publication. While the subject is still one to which the attention of members is earnestly urged, the Editor desires gratefully to acknowledge a marked improvement in the mechanical arrangement of papers. This has saved labor, time and expense and promoted accuracy.

The cost of each of the five volumes thus far issued by the Society is as follows:

| | Vol. 1. (pp. 593; pls. 13) | Vol. 2. (pp. 662; pls. 23) | Vol. 3. (pp. 541; pls. 10) | Vol. 4. (pp. 458; pls. 10) | Vol. 5. (pp. 665; pls. 21) |
|---|---|---|---|---|---|
| Letter-press. | $1,473 77 | $1,992 52 | $1,535 59 | $1,286 39 | $1,887 21 |
| Illustrations. | 291 85 | 463 65 | 383 35 | 173 25 | 178 40 |
| | $1,765 62 | $2,456 17 | $1,918 94 | $1,459 64 | $2,065 61 |

A comparison of the above totals will plainly show that, in view of its size and fullness of illustration, volume 5 was far from being an expensive publication.

The general shrinkage in prices during the past year has enabled the Society to renew its printing contract with Messrs Judd & Detweiler at somewhat lower rates. This, together with the reduction of the edition from 750 to 500 copies, will result in considerable saving to the Society.

Respectfully submitted.

JOSEPH STANLEY-BROWN,
*Editor.*

WASHINGTON, D. C., *December 20, 1894.*

On motion of the Secretary, it was voted to defer action upon the Council's report until the morning session of Friday.

As the Auditing Committee to examine the Treasurer's accounts the Society elected J. S. Diller and B. K. Emerson.

### *ELECTION OF OFFICERS*

The result of the balloting for officers for 1895, as canvassed by the Council, was announced by the Secretary, and officers were declared elected as follows:

*President:*

N. S. Shaler, Cambridge, Mass.

*First Vice-President:*

Joseph Le Conte, Berkeley, Cal.

*Second Vice-President:*

Charles H. Hitchcock, Hanover, N. H.

*Secretary:*

H. L. Fairchild, Rochester, N. Y.

*Treasurer:*

I. C. White, Morgantown, W. Va.

*Editor:*

J. Stanley-Brown, Washington, D. C.

*Councillors (term expires 1897):*

R. W. Ells, Ottawa, Canada.
C. R. Van Hise, Madison, Wis.

### *ELECTION OF FELLOWS*

The result of the balloting for Fellows, as canvassed by the Council, was announced, and the following persons were declared elected Fellows of the Society:

Julius Morgan Clements, B. A., Ph. D., Madison, Wisconsin. Assistant Professor of Geology in the University of Wisconsin.

Collier Cobb, A. B., A. M., Chapel Hill, North Carolina. Professor of Geology in the University of North Carolina.

Thomas C. Hopkins, A. M., Chicago, Illinois. Fellow in Geology at the University of Chicago.

Lucius Lee Hubbard, A. B., LL. B., A. M., Ph. D., Houghton, Michigan. State Geologist of Michigan.

Josiah Edward Spurr, A. B., A. M., Gloucester, Massachusetts.

### *AMENDMENTS TO THE CONSTITUTION*

It was announced that the proposed changes in the Constitution which failed to receive the required vote at the previous annual meeting had

been resubmitted to the Society, and that the transmitted ballots, canvassed by the Council, showed an affirmative vote of three-fourths of the total membership. The following amendments to the Constitution were therefore adopted :

Article III, section 1, amended by omitting the closing words of the section, "and resident in North America," so that the section reads: "1. Fellows shall be persons who are engaged in geological work or in teaching geology."

Article IV, section 8, amended by inserting after the word "Editor" the words "and Treasurer," so that the paragraph reads: "The Secretary, Editor and Treasurer shall be eligible to reëlection without limitation."

### *AMENDMENTS TO THE BY-LAWS*

The proposed change in the By-Laws recommended by the Council at the Brooklyn meeting and announced in the Secretary's circular of September 6, 1894, was declared in order under unfinished business, and after explanations by the Secretary and Treasurer the amendment was unanimously voted as follows :

Chapter VII, section 1, amended by omitting the words, "of moneys paid by the general public for publications of the Society," so that the section reads: "1. The Publication Fund shall consist of donations made in aid of publication, and of the sums paid in commutation of dues, according to the By-Laws, chapter I, clause 2."

Professor W. B. Clark, representing the Local Committee of Entertainment, made announcement concerning the signing of railroad certificates for reduced rates, and also extended to the Fellows in behalf of the University Club the hospitality of the Club.

Under the heading in the program of "Necrology" the following memorials of deceased Fellows were read :

### *MEMORIAL OF GEORGE HUNTINGTON WILLIAMS*

BY WILLIAM B. CLARK

Although the world always mourns the departure of a true man, the sense of loss is keener when the life which is taken has not reached its full fruition ; when the work done indicates still greater achievements, could the full period of activity have been filled out. Such must ever be the feelings of those who mourn the loss of Professor George H. Williams, who, in the full vigor of manhood, passed away on July 12, at the home of his father, in Utica, New York, a victim to the ravages of a fever contracted while earnestly pursuing his geological investigations in the Piedmont area of Maryland—a region which he has made classic for all subsequent students of American petrography.

George Huntington Williams was born in Utica, New York, on January 28, 1856. He was the eldest son of Robert S. and Abigail (Doolittle) Williams, whose ancestry was of the sturdy Puritan type, the great-grandparents of both having emigrated from New England toward the close of the last century. His paternal ancestors were for two generations successful tanners, and his grandfather was a well-known printer and publisher; a prominent man of affairs and a colonel in the war of 1812. His father is today an influential man in many of the greater enterprises in the commercial life of his native city. One of his uncles was the eminent author and Chinese lexicographer, Dr S. Wells Williams, who by long residence at Pekin, a portion of the time as representative of our Government, attained a position of distinction and influence, and who, after his return to America, became professor in Yale University. Another uncle, the Reverend F. W. Williams, was a missionary to Syria, and was one of the first to make explorations upon the site of ancient Nineveh.

Surrounded in his youth by the refinements which an educated family life can give, our friend spent his school days in Utica, passing through the various grades of the public schools, and finally graduating with valedictory honors from the Utica Free Academy. Less robust than many of his fellow-students, he sought his pleasures more largely than they in reading, for which the well stocked library in his own home gave him exceptional opportunity. Systematic and conscientious to the last degree in every detail connected with his school life, he then formed habits of mind which characterized his maturer years. In a remarkable degree the boy was father to the man.

In the autumn of 1874 he entered Amherst College, graduating in the class of 1878. He carried into this new field of study the same system which had characterized his school life, and his classmates recount the scrupulous care with which he prepared outlines of every class-book used or course of lectures given, thus readily becoming master of all that the college required.

Toward the close of his college course he came under the tutelage of that exceptional teacher and geologist, Professor B. K. Emerson, who has sent forth so many young men full of enthusiasm for his subject to take it up as their life-work. Such was the result in this instance. The deep interest of the teacher became communicated to the student, and the young man of twenty-two decided to give up his life to geology. He remained much of the year succeeding graduation at Amherst, where he continued his studies with Professor Emerson. In the spring of 1879 he returned to Utica, and taught science for a time with marked success in the academy from which he had graduated five years before.

Deciding to pursue his studies in Europe, he went to Germany in July of the same year, and spent the summer and early autumn in perfecting himself in the German language at Brunswick, going to Göttingen at the opening of the winter semester. For a year he attended the lectures of the renowned Professor Klein, which gave a decided mineralogical trend to his future work.

The summer of 1880 was employed in an extended journey to southern and eastern Europe. Italy and Greece were visited and their classic volcanic areas studied, and the trip was extended to Constantinople and the Danube.

Upon his return to Germany in the autumn of 1880 he decided to continue his university studies at Heidelberg, where the great teacher, Professor Rosenbusch, was drawing to his laboratory those who were anxious to enter the comparatively new domain of microscopical petrography. It was here that the young geologist acquired the exact methods of investigation that so fully characterized his later work. For more than two years Mr Williams remained under his distinguished teacher, and in December of 1882 received the degree of Doctor of Philosophy.

His thesis, which, with the exception of a single short article, was the first of his scientific publications, dealt with the eruptive rocks of the region of Tryberg, in the Black forest. It was a valuable paper, and at once attracted the attention of geologists.

Dr Williams returned to his home at the close of 1882, and during a visit to Baltimore in the following March was offered, and accepted, the position of Fellow by Courtesy in the Johns Hopkins University. A year later he became a member of the academic staff, with the title of Associate, which position he held until 1885, when he was made an Associate Professor. In 1892 he became Professor of Inorganic Geology.

From his entrance into the service of the University Dr Williams directed his attention to a study of Maryland geology, and more especially to the Piedmont area lying to the west of Baltimore. Important problems in rock metamorphism here presented themselves, and as a result of this study numerous contributions were made to scientific journals in this country and in Europe. The most important of these publications is "The gabbros and associated hornblende rocks occurring in the neighborhood of Baltimore."* Another valuable production is a pamphlet dealing with the minerals occurring in the same region. Much of the work in the Maryland area was done under the auspices of the United States Geological Survey, with which organization Dr Williams was closely connected ever after his return to America. He valued these opportunities for investigation afforded by the immediate region not only

* Bulletin 28 of the U. S. Geological Survey.

as a field for personal research, but also as nature's laboratory, in which young men might be trained in the most exact methods of scientific investigation. From the very first his enthusiasm and his luminous manner of interpretation drew students to him, while his devotion to their interests made a close bond of sympathy which lasted beyond their student days.

While engaged primarily in the study of the geology of Maryland, Dr Williams took up other problems during his absence from Baltimore in vacation time, collecting data and materials that formed the basis for more extended examination in the laboratory. One of the most significant investigations of this character dealt with the "Cortlandt series of the Hudson and the contact phenomena produced on the adjoining schists and limestones." A series of papers upon this subject was published in the American Journal of Science.

The summers of 1884 and 1885 were spent in the Menominee and Marquette regions of Michigan, and the observations made upon the greenstone-schists of those areas and the later microscopic study of the material collected, constitute the largest single contribution made by Professor Williams to geologic literature.* Besides the discussion of the detailed geology, this publication is a complete digest of the subject of metamorphism in its relations to eruptive rocks.

During the summer of 1888 Professor Williams joined his former teacher, Professor Rosenbusch, and several of the leading geologists of Norway, upon an expedition to portions of that country, where problems not unlike those which he had had under consideration in America gave him an abundance of comparative material and a great fund of information for his class-room work.

Meanwhile Professor Williams had prepared many smaller essays upon both mineralogical and geological topics, while numerous reviews of current American petrographical literature appeared in scientific journals, both at home and abroad. As expert editor upon mineralogy and petrography for the Standard Dictionary and Johnson's Cyclopedia, he either personally prepared the articles relating to those subjects or carefully supervised the work of others. From the first an associate editor of the Journal of Geology, he frequently contributed to its columns.

Although so actively engaged in scientific work, the needs of the class-room were kept constantly in view. The lack of a suitable text-book for students in crystallography led to the preparation of his "Elements of Crystallography," which has come to be almost universally used, both in

* The volume, containing some 250 pages, with numerous plates, appeared as Bulletin 62 of the U. S. Geological Survey.

this country and in England, and whose value is attested by the fact that it has already passed through several editions.

In the invention of mechanical appliances to facilitate petrographic work, Professor Williams showed especial aptitude. He devised an electrical machine for cutting and grinding thin-sections of rocks, and also aided in the perfecting of the only satisfactory petrographical microscope manufactured in this country.

When the World's Fair Commissioners of Maryland desired the preparation of a volume in which the resources of the state should be suitably presented, an appeal was made to the Johns Hopkins University, and Professor Williams was appointed chairman of the committee which had the matter in charge. He contributed largely to the book, writing upon the geology and mineral resources of the state and preparing a geological map which is a most important addition to our knowledge of the geological formations.

The work of Professor Williams upon the Piedmont area of Maryland led to the discovery, in the South Mountain district of Pennsylvania and its extension into Maryland, of ancient volcanic rocks of both acid and basic types which present all the essential features of modern eruptives. This occurrence suggested the probable extension of similar rocks along the eastern border of the continent, a point fully corroborated by a proper interpretation of the older literature and a study of the material specially collected by himself and others. It was the intention of Professor Williams more fully to investigate this subject, and plans had been formed for field observation in the north during the past summer.

During the last academic year extensive preparation had been made for the publication of a general work upon the crystalline schists, which would have presented the maturer views of Professor Williams upon this important subject. An elaborate course of lectures was delivered to his students, in which the outline of the prospective volume was given.

Other lines of work were under consideration, but the end came before they could be undertaken.

Professor Williams was honored with membership in many scientific societies. He was a corresponding member of the Geological Society of London and of the French Mineralogical Society, and at its last meeting was elected one of the vice-presidents of the Geological Society of America. As one of the judges of award in the department of mines and mining at the World's Fair, he was requested to prepare the report upon the exhibits of minerals and gems.

Professor Williams appeared often on public occasions, where his

ability as a speaker brought him into sympathy with his hearers and made it possible to interest them in the more vital problems of his chosen science. Several addresses and popular articles of this nature were prepared, which have done much to bring before those not particularly trained in petrography a knowledge of its aims and methods. As one of the pioneers in American petrography, he has done as much as any one to advance its claims. His many contributions to scientific literature, his success as a teacher, and his ability on the lecture platform, have been among the most potent influences in making the subject of microscopical petrography one of the most popular branches of geology in America at the present time. An address was delivered before the Johns Hopkins University two years ago, on Commemoration Day, upon "A University and its Environment," in which some of the wider applications of geology were forcefully presented.

In the broader relations of life, outside the sphere of investigation and instruction to which the chief energies of Professor Williams were devoted, he was always a positive force. The interests of the university, which he served during a period of nearly twelve years, were ever before him, and, whenever the opportunity offered, he sought its advancement with a loyalty which was cordially appreciated by all friends of the institution.

As a man Professor Williams was a staunch and loyal friend, with a generosity of nature which deeply endeared him to those with whom he came in close personal relations. It was a pleasure to him when his services could in any way be of benefit to those about him.

His untimely death is an irreparable loss to the science which he had done so much to advance, to the university in which he held a place of such prominence, and to the wide circle of friends which he had drawn about him.

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In testimony of regard to the memory of Dr Williams tributes were paid by B. K. Emerson, his first teacher in geology; J. F. Kemp, a college-mate, and by his friends and colleagues, J. P. Iddings, I. C. White, C. D. Walcott, W. S. Bayley and N. S. Shaler.

## *MEMORIAL OF AMOS BOWMAN*

BY H. M. AMI

Amos Bowman, whose death was announced* at the Brooklyn meeting, on the 14th of August last, was elected Fellow of this Society in May, 1889. He was born in Blair, Waterloo county, Ontario, Canada, September 15, 1839. When a youth his parents removed to Waterville, Ohio. In 1856, when only seventeen, he went to New York city to study medicine. There he did considerable journalistic work. From New York he went to California in its early days, and became connected with the Sacramento Union, the leading paper of that state. Mr Bowman is next seen in Germany, where he spent nearly three years in pursuing and completing a course in civil and mining engineering.

He visited Russia, Austria and other countries in Europe, on which he wrote several articles for the American press. He attended lectures at Freiberg and Münich, and, returning to California, was brought in contact with many public men, especially through articles in the columns of both the New York Tribune and the Sacramento Union, with the latter of which he was connected for some five years.

His first survey work was done in 1863, at the age of twenty-four, when he assisted in the survey of the boundary line between California and Nevada. He was largely instrumental in getting the appropriation granted for the organization of the Geological Survey of California under J. D. Whitney, then professor of geology at Harvard. In 1868 he was appointed to a position in the Geological Survey of California, and, owing to the numerous duties devolving upon its director in the east, Mr Bowman in his absence had charge both of the field and office work, duties he discharged for several years, until the close of the survey.

From 1873 to 1876 he was engaged in survey work for private mining corporations. The most important of these was embodied in a mining and topographic report on the Georgetown divide, published in 1874.

Mr Bowman was the first to define the terraces along the Pacific coast—in Washington territory and adjacent shores, and contributed a chapter on "Pliocene rivers of California" in the "Report of the United States Mineral Resources for 1873."

In British Columbia, Mr Bowman began work in 1876 as assistant to Dr G. M. Dawson. As a joint employe of the provincial government of

* Bull. Geol. Soc. Am., vol. 6, 1894, p. 1.

He died of acute Bright's disease on the 18th of June, 1894, at his home on Cap Santé, Washington. This disease was doubtless aggravated, if not induced, by a severe cold and complication of disorders, brought on by undue exposure and hardships endured in a severe storm off the west coast on his way to Victoria, British Columbia, whither he was going to complete a report on a section of that province for the local authorities.

British Columbia and of the Geological Survey of Canada he remained more or less continuously during the remainder of his life.

In 1885 he was intrusted with the survey and investigation of the well known placer-mining region of Cariboo, British Columbia, which comprises an area of some 4,000 square miles. The result of his work forms a report addressed to Dr Selwyn, the Director of the Canadian Survey, and was published as volume iii of the new series. He is reputed to have introduced the cable-car system in San Francisco.

Early in his travels he was impressed with the location of Fidalgo island and took his family there in 1877. He was the founder of Anacortes, called after his wife, Anna Curtis, whom he married in April, 1871. Mrs Bowman survives her husband, who leaves behind him four children, a daughter and three sons.

He was of an affable and generous disposition, an enthusiast in everything he undertook, not always to his advantage, and unfortunately died before seeing many of his schemes realized.

I am indebted to Dr G. M. Dawson, to Dr A. C. Lawson, to Mr James White and to the widow of our late Fellow for information contained in this brief notice of his life and writings.

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Map of Cariboo mining district, British Columbia. Scale = 2 miles to 1 inch. 1887.

In addition to the above, Mr Bowman's report on the Cariboo mining district contains detailed mining maps of—

(*a*) Mosquito creek.
(*b*) Williams creek.
(*c*) Hixon creek.
(*d*) Lightning creek.
(*e*) Antler creek.
(*f*) Cunningham creek.
(*g*) Keithly creek.
(*h*) Sugar creek.
(*k*) Harvey creek.
(*l*) Grouse creek.

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The presentation of scientific papers was declared in order, under the rule applied at the two previous meetings, and the first paper read was—

*CERTAIN FEATURES IN THE JOINTING AND VEINING OF THE LOWER SILURIAN LIMESTONES NEAR CUMBERLAND GAP, TENNESSEE*

BY N. S. SHALER

The second paper was—

*THE APPALACHIAN TYPE OF FOLDING IN THE WHITE MOUNTAIN RANGE OF INYO COUNTY, CALIFORNIA*

BY CHARLES D. WALCOTT

Remarks on the matter of the paper were made by I. C. Russell, Bailey Willis, George F. Becker and H. M. Ami. The paper is printed in the American Journal of Science, volume xlix, page 169.

Mr H. F. Reid, for the Local Committee, made announcement of the hour for the evening reception, and a recess for luncheon was taken.

The Society reconvened at 2 o'clock p m, Vice-President N. S. Shaler in the chair.

The first paper read was—

*NEW STRUCTURAL FEATURES IN THE APPALACHIANS*

BY ARTHUR KEITH

The paper was discussed by C. W. Hayes, Bailey Willis, the Chairman, and by the author in reply.

The next paper was—

*FAULTS OF CHAZY TOWNSHIP, CLINTON COUNTY, NEW YORK*

BY H. P. CUSHING

Remarks were made by C. D. Walcott, N. S. Shaler and H. M. Ami. The paper is printed as pages 285–296 of this volume.

The following paper was then presented:

*FORMATION OF LAKE BASINS BY WIND*

BY G. K. GILBERT

Remarks on the matter of the paper were made by W J McGee, I. C. White, N. S. Shaler. The paper is published in the Journal of Geology, volume iii, 1895, pages 47–49.

The next paper, illustrated by lantern views, was:

*TEPEE BUTTES*

BY G. K. GILBERT AND F. P. GULLIVER

Remarks were made by H. S. Williams and the chairman, with replies by the senior author. The paper is printed as pages 333–342 of this volume.

The following paper was presented informally:

*REMARKS ON THE GEOLOGY OF ARIZONA AND SONORA*

BY W J MCGEE

In the absence of the authors the following two papers were read by title:

*HIGHWOOD MOUNTAINS OF MONTANA*

BY WALTER H. WEED AND LOUIS V. PIRSSON

This paper is printed as pages 389–422 of this volume.

*GENESIS AND STRUCTURE OF THE OZARK UPLIFT*

BY CHARLES R. KEYES

The last paper of the session was—

*THE GEOGRAPHICAL EVOLUTION OF CUBA*

BY J. W. SPENCER

The Society then, at 5.45 o'clock p m, adjourned. No evening session was held, the Fellows being invited by the Johns Hopkins University to a social assembly in McCoy hall, in conjunction with the American Society of Naturalists and other societies.

## Session of Friday, December 28

The Society was called to order at 10 o'clock a m, President Chamberlin in the chair.

On motion of Professor R. D. Salisbury, the report of the Council which had been distributed in print the previous day, was unanimously adopted without debate.

### *REPORT OF AUDITING COMMITTEE*

The report of the Auditing Committee was read by Professor B. K. Emerson, as follows:

*To the Geological Society of America:*

Your committee, appointed to audit the accounts of the Treasurer for the year ending November 30, 1894, have made the necessary examination and have found them correct.

The committee recommends that the Society approve the action of the Council in directing the Treasurer to draw upon the receipts from sales of the Bulletin to pay current expenses to the extent of $658.41; and they further recommend that this amount be not repaid into the publication fund, and that the $119.78 of receipts from sale of publications not yet expended be available for current expenses.

J. S. Diller,
B. K. Emerson,
*Committee.*

Baltimore, *December 27, 1894.*

The report of the Auditing Committee was adopted with its recommendations.

The following report of the Photograph Committee was presented by Mr J. S. Diller, the chairman, and read by the Secretary:

### *FIFTH ANNUAL REPORT OF COMMITTEE ON PHOTOGRAPHS*

Two hundred and ninety-two views have been added to the collection during the year. It now numbers 1,094, and will hereafter be in the hands of Mr G. P. Merrill, chairman of the Committee on Photographs. The donors are R. D. Salisbury (4), United States Geological Survey, C. D. Walcott, Director (220), and William Libbey, Jr. (68).

Donations are solicited as heretofore, and may be sent to Mr G. P. Merrill, National Museum, Washington, D. C.; Professor J. F. Kemp, Columbia College, New York city, or Professor W. M. Davis, Harvard College, Cambridge, Massachusetts.

REGISTER OF PHOTOGRAPHS RECEIVED IN 1894

*Photographed and presented by Professor R. D. Salisbury, University of Chicago, Chicago, Illinois*

803. Roche moutonnée (trap), one mile east of Englewood, New Jersey, on Palisade avenue; showing broad, deep grooves. Size, 7 x 9 inches.
804. Glaciated surface of trap exposed by the excavation for the water-works reservoir at Weehawken, New Jersey. In addition to the glaciation of the surface, the photograph shows the phenomena of "plucking." Size, 7 x 9 inches.
805. Perched block of Triassic sandstone, 12 x 8 x 8 feet, on Palisade ridge, east of Englewood, New Jersey, near the summit. Beneath the bowlder the trap surface shows polishing and grooving, but where the surface has not been protected the polishing and grooves have disappeared by weathering. The bowlder has probably been lifted something like 180 feet. Size, 7 x 9 inches.
806. Glaciated surface of trap exposed by the excavation for the water-works reservoir at Weehawken, New Jersey. In addition to the glaciation of the surface, the photograph shows the phenomena of "plucking." Size, 7 x 9 inches.

*Presented by the United States Geological Survey, C. D. Walcott, Director*

Twenty-eight (10 x 13) photographs by J. K. Hillers

807. El Capitan from the trail, Yosemite valley, California.
808. Cathedral spires, Yosemite, California.
809. Shingle, Yosemite, California.
810. Yosemite Falls cliff, California.
811. Three Brothers, Yosemite valley, California.
812. Kings river, California.
813. The Jungle, Kings river, California.
814. Moores cliff, Kings river, California.
815. Cabin point, Kings river, California.
816. Junction cliff, Kings river, California.
817. Sentinel cliff, Kings river, California.
818. Doe River gorge, Tennessee.
819. Doe River gorge, Tennessee.
820. Cranberry iron mines, North Carolina.
821. View on the French Broad, North Carolina.
822. Cranberry iron works, North Carolina.
823. Looking north toward Asheville from High point, North Carolina.
824. Marble quarry, Knoxville, Tennessee.
825. View on the French Broad, North Carolina.
826. Doe River gorge, Tennessee.
827. View on the French Broad, North Carolina.
828. Hickory Nut gap, North Carolina.
829. From the top of Blue Ridge gap, North Carolina, looking west.
830. From the top of Blue Ridge gap, looking east.
831. Hickory Nut gap, North Carolina.
832. View of the French Broad, North Carolina.
833. Cranberry iron mines, North Carolina.
834. Model farm, North Carolina.

Seventy (6 x 8) photographs by C. D. Walcott

835. Mouth of Silver canyon, White Mountain range, Inyo county, California; showing delta, Quaternary beds and mountain of Cambrian limestone and quartzite.
836. Overturned fold in Cambrian quartzites, north side of Silver canyon, White Mountain range, Inyo county, California.
837. West limb of overturned synclinal, Silver canyon, White Mountain range, Inyo county, California. The dark portions are compressed shales in synclinal.
838. The Sierra Nevada from Alvord station, two miles east of Big Pine, Inyo county, California.
839. Cambrian quartzites showing vertical cleavage of the strata. Soldiers canyon, Deep Spring valley, Inyo county, California; White Mountain range.
840. Lower Cambrian quartzites showing vertical cleavage in massive layers and interbedded thin layers without cleavage. Soldiers canyon, above Deep Spring valley, White Mountain range, Inyo county, California.
841. Lower Cambrian quartzites showing vertical cleavage in massive layers and interbedded thin layers without cleavage. Soldiers canyon, above Deep Spring valley, White Mountain range, Inyo county, California.
842. Nearer view of quartzite cliff on south side of Soldiers canyon, above Deep Spring valley, White mountain range, Inyo county, California.
843. Hill two miles west of Big Pine, Inyo county, California; showing outcrop of Paleozoic (?) rocks, with eruptive rocks (granite) to the west. Right side.
844. View of low hills one mile southwest of Antelope springs, Deep Spring valley, Inyo county, California; showing synclinal in Cambrian limestones resting on quartzites.
845. View of low hills one mile southwest of Antelope springs, Deep Spring valley, Inyo county, California; showing synclinal in Cambrian limestones resting on quartzites.
846. View of granitic mountain range on side of Deep Spring valley, Inyo county, California.
847. Overlooking granite area on east slope of White Mountain range, from near divide on road leading from Deep Spring valley, California, to Fish Lake valley, Nevada.
848. View of Deep Spring valley, Inyo county, California; showing folded Cambrian strata on northwestern side of valley, as seen from the west.
849. The Sierra Nevada from Alvord station, two miles east of Big Pine, Inyo county, California.
850. Outline of crest of Sierra Nevada west of Big Pine, Inyo county, California; from Tollgate canyon, White Mountain range.
851. Different view, but same label as 850.
852. Panoramic view of a section of the White Mountain range north of road passing from Big Pine, Inyo county, California, to Deep Spring valley.
853. Panoramic view of White Mountain range, Inyo county, California; from foothills of Sierra Nevada, looking across Owens valley.
854. Different view, but same label as 853.
855. Different view, but same label as 853.

856. Different view, but same label as 853.
857. Different view, but same label as 853.
858. White Mountain range directly east of Alvord station and north of Tollgate canyon, Inyo county, California.
859. Granite bowlders resulting from the disintegration of massive granite, eastern slope of Sierra Nevada, three miles west of Big Pine, Inyo county, California.
860. Granite bowlders resulting from the disintegration of massive granite, eastern slope of Sierra Nevada, three miles west of Big Pine, Inyo county, California.
861. Hill on north side of Deep Spring valley, Inyo county, California; showing strongly marked cleavage in the granite.
862. Block of granite showing cleavage planes; north side of Deep Spring valley, Inyo county, California.
863. West end of ridge, giving a nearer view of the cleavage in the granite.
864. Bowlders resulting from disintegration of granite; north side of Deep Spring valley, Inyo county, California.
865. Plicated layers of thin bedded chert in limestone etched by erosion. Lower (?) Cambrian (?). Hill two miles west of Big Pine, Inyo county, California.
866. Plicated layers of thin bedded chert in limestone etched by erosion. Lower (?) Cambrian (?). Hill two miles west of Big Pine, Inyo county, California.
867. Different view, but same label as 866.
868. Different view, but same label as 866.
869. Mountains west from Hiko, Nevada.
870. Unconformity of Quaternary and Paleozoic; looking east from Panaca, Nevada.
871. Volcanic rocks west of Pahroc spring, Nevada.
872. Mountains west from Hiko, Nevada.
873. Permian cliff east of Toquerville, Utah.
874. Summit of Carboniferous limestone. Hurricane cliff about 10 miles south of Toquerville, Utah.
875. Unconformity between Carboniferous and Permian. On Hurricane cliff, 10 miles south of Toquerville, Utah.
876. Looking toward the cliffs from south of Virginia City, Utah.
877. Permian cliff east of Toquerville, Utah.
878. Contact of Silurian sandstone on pre-Paleozoic gneiss and schists; looking north from below the spring west of the Harding sandstone quarry, one mile north of the Arkansas river and one mile and a half northwest of Canyon City, Colorado.
879. Shales, broken down by superincumbent weight, or creeping; half a mile north of Columbia, Lancaster county, Pennsylvania; beside Pennsylvania railroad tracks.
880. Different view, but same label as 879.
881. Cliff of massive bedded Lower Cambrian limestone, bluish black at the base, white above and capped by thinner layers of a dark arenaceous limestone. Quarries on the line of the Pennsylvania railroad at Bellemont, Lancaster county, Pennsylvania.
882. A closer view of the cliff. Quarries at Bellemont post office, Lancaster county, Pennsylvania, on the line of the Pennsylvania railroad.
883. Quarry near Bellemont post office, Lancaster county, Pennsylvania. This quarry shows the brecciation, caused by jointing and cleavage planes, of the massive limestone shown in 881.

884. Lower Cambrian limestone, exposed in quarries at Bellemont, Lancaster county, Pennsylvania, on line of Pennsylvania railroad, a little east of 881. The massive limestones of 881 are here capped by a band of conglomerate limestone which rests on the thin bedded limestone shown in the top of quarry.
885. Banded Lower Cambrian rocks, just southwest of Emigsville, York county, Pennsylvania.
886. Synclinal fold in Lower Cambrian limestone. Limestone quarry of the east side of York, Pennsylvania, within the city limits.
887. Exposure of limestone conglomerate in Lower Cambrian limestone, in a quarry on the east side of York, Pennsylvania, within the city limits.
888. Conglomerate limestone. Quarry quarter of a mile north of Stoners station, York and Wrightsville railroad, York county, Pennsylvania.
889. Portion of massive layer of conglomerate limestone. Quarry quarter of a mile north of Stoners station, York and Wrightsville railroad, York county, Pennsylvania.
890. Plane of overthrust fault, north side of river, below Highgate falls, Vermont.
891. Summit of an anticlinal fold, four miles west of West Arlington, Vermont.
892. Plicated slates, one and a half miles east of Wells post office, Rutland county, Vermont.
893. Plane of overthrust fault, north side of river, below Highgate falls, Vermont.
894. Little Rock island, Highgate springs, Vermont.
895. Exterior view of Dixon plumbago mine, four miles west of Hague, Warren county, New York.
896. Cut in drift about one mile northwest of Gravesville, Herkimer county, New York.
897. City of Quebec; from point Levis, Canada.
898. Conglomerate of limestone, quartz, trap, etcetera, bowlders, situated about 1,500 feet down in Sillery red shales, five miles below Quebec, Canada, on south shore of Saint Lawrence river. Dr R. W. Ells, of the Geological Survey of Canada, in view.
899. Illustration of the decay of the upper semicrystalline beds of the Trenton limestone at Rusts quarry, on east bank of West Canada creek, above Trenton Falls, New York.
900. "High falls," Trenton Falls, New York.
901. Distant view of "High falls," at Trenton Falls, New York.
902. Bowlder imbedded in crystalline Algonkian limestone, one mile north of Fort Ann, Washington county, New York, on roadside to Comstocks.
903. Large bowlder in crystalline Algonkian limestone, one mile north of Fort Ann, on roadside to Comstocks, Washington county, New York.
904. Interior of Dixon plumbago mine, four miles west of Hague, Warren county, New York.

Thirty-four (6 x 8) photographs taken in Yellowstone National Park, with one exception, by J. P. Iddings and W. H. Weed.

905. Yellowstone lake, showing Absaroka range.
906. Big Horn park, Gallatin range.
907. Dikes near Hoodoo mountain.

908. Glacial bowlder, brink of Yellowstone canyon.
909. Erratic bowlders, Pleasant valley.
910. Basalt cliff, near Tower falls.
911. Hoodoo temple, Hoodoo basin.
912. Hoodoos, Hoodoo basin.
913. Lithophysæ, half a mile above falls on lower Fire Hole river.
914. Lithophysæ, half a mile above falls on lower Fire Hole river.
915. Keplers cascade, Fire Hole river, Upper Geyser basin.
916. Spring in Gallatin canyon, Gallatin range.
917. Emerald Creek falls; basalt cliffs.
918. Tower falls.
919. Rustic falls, Glen lake.
920. Keplers cascade, Fire Hole river, Upper Geyser basin.
921. Face of natural bridge of rhyolite, Bridge creek.
922. Natural bridge of rhyolite, Bridge creek.
923. Small geyser in eruption, in Upper Geyser basin.
924. Rustic geyser in eruption, Middle Geyser basin.
925. Runway of Indigo spring.
926. Outlet of Excelsior geyser.
927. Algæ basins (showing formation of silicious sinter), Emerald spring, Upper Geyser basin.
928. Spike geyser, Witch creek.
929. Silicious sinter from Coral spring.
930. Gallatin lake, head of Gallatin river, one of the three forks of the Missouri.
931. Bannock peak, Gallatin range.
932. Yellowstone canyon, opposite Tower falls.
933. Basalt cliff near Tower falls.
934. Basalt cliff near Tower falls.
935. Intrusive basalt, showing columns of cooling, Orange quarry, New Jersey.
936. Petrified tree trunk, Fossil forest.
937. Fossil tree trunks, Fossil forest.
938. Petrified tree trunk. Lamar valley in distance.

Sixty-one (6 x 8) photographs taken by N. H. Darton.

939. Potsdam sandstone lying on crystalline rocks, just below Jessups landing, on Hudson river, Saratoga county, New York. Looking south. Shows thin bedded sandstones and basal conglomerates and many points of actual contact with crystalline rocks.
940. Potsdam sandstone lying on crystalline rocks, just below Jessups landing, on Hudson river, Saratoga county, New York. Shows thin bedded sandstones and basal conglomerates and many points of actual contact with the crystalline rocks. Published as a plate in report of state geologist of New York for 1893.
941. Potsdam conglomerate on crystalline rocks near Mosherville, Saratoga county, New York. Published as a plate in report of state geologist of New York for 1893.
942. Glaciated surface of Potsdam conglomerate near Mosherville, Saratoga county, New York. Published as a plate in report of state geologist of New York for 1893.

943. Glenns falls, on Hudson river. Looking west. Published as a plate in report of state geologist of New York for 1893.

944. Quarry in Trenton limestone, south bank of Hudson river, Glenns Falls, New York.

945. Trenton, Black River and Birdseye limestones on Calciferous, north bank of Hudson river, Glenns Falls, New York. Published as a plate in report of state geologist of New York for 1893.

946. Lake in drift hills, southwest of Glenns Falls, New York. Looking north. French mountain in the distance.

947. Calciferous on crystalline schists, West Shore railroad cut one mile west of Downing station, New York. Looking south. Published as a plate in report of the state geologist of New York for 1893.

948. Calciferous sandrock on East Canada creek, two miles above its mouth, Herkimer county, New York.

949. Calciferous on East Canada creek, one mile above its mouth, Herkimer county, New York. Published as a plate in report of state geologist of New York for 1893.

950. Fault and dike in east bank of East Canada creek, a mile above its mouth, Herkimer county, New York. Published as a plate in report of state geologist of New York for 1893.

951. Fault and dike in east bank of East Canada creek, one mile above its mouth, Herkimer county, New York, looking east. On the left is Calciferous, with a breccia along the fault plane. In the center is the dike, which is a melilite-diabase. On the right are Trenton limestones below and shales and thin sandstones of the Utica formation above. The central opening is an adit made by prospectors. Published as a plate in report of the state geologist of New York for 1893.

952. Trenton limestones overlain by Utica shales in ravine behind Canajoharie, New York.

953. Utica shales, Trenton limestones and Calciferous sandrock in banks of creek behind Canajoharie, New York. Published as a plate in report of state geologist of New York for 1893.

954. Ravine in Utica shales behind Canajoharie, New York. Published as a plate in report of state geologist of New York for 1893.

955. Gorge of Mohawk river, at Little Falls, New York. Calciferous in the foreground and to the left. Crystalline rocks along the river to the left and hills of Utica shale in the background. Looking west.

956. The principal falls of Trenton Falls, New York, over Trenton limestone. Published as a plate in report of state geologist of New York for 1893.

957. Cascade in upper gorge at Trenton Falls, New York, over Trenton limestone. Published as a plate in report of state geologist of New York for 1893.

958. Lower portion of gorge at Trenton Falls, New York. Published as a plate in report of state geologist of New York for 1893.

959. Spencer falls, Trenton Falls, New York, over Trenton limestone. Published as a plate in report of state geologist of New York for 1893.

960. Quarry at Howe's cave, Schoharie county, New York. Pentamerus and tentaculite beds of the Helderberg limestone. Published as a plate in report of state geologist of New York for 1893.

961. The Helderberg escarpment south of Indian Ladder, Albany county, New York; looking southwest. Slopes of Hudson shale in the foreground. High cliffs of Pentamerus beds of the Helderberg, surmounted by terraces of overlying limestones. Hills of Hamilton group in the background to the right.

962. The Helderberg escarpment at Indian Ladder, Albany county, New York. Slopes of Hudson shale, cliffs of tentaculite, and pentamerus limestones. Looking south.

963. Part of panorama to the westward of 962, showing the "gulf" at Indian Ladder. Published as a plate in report of state geologist of New York for 1893.

964. Pentamerus and tentaculite beds of Helderberg limestone at Indian Ladder, Albany county, New York. Published as a plate in report of state geologist of New York for 1893.

965. Quarry in Helderberg limestones just south of South Bethlehem, Albany county, New York. Exhibits tentaculite and pentamerus beds, which are extensively used for road metal. Looking south. Published as a plate in report of state geologist of New York for 1893.

966. Road metal quarry in pentamerus and tentaculite beds of Helderberg limestones, at South Bethlehem, Albany county, New York.

967. Creek falling into limestone cave (pentamerus beds of Helderberg limestone), west of Coxsackie, New York. Published as a plate in report of state geologist of New York for 1893.

968. Overturn and fault of Sprayt creek, one mile west of South Bethlehem, Albany county, New York. To the left are the Hudson shales, exhibiting an overturned anticlinal with nearly horizontal axis. They are overlain by thin bedded Helderberg limestones, and at the top are heavier bedded limestones, which are overthrust along a fault plane which is seen in the middle of the right-hand side of the photograph. Published as a plate in report of state geologist of New York for 1893.

969. Anticlinal in Esopus shales (Cauda galli), Catskill creek, near Leeds, Green county, New York. Published as a plate in report of state geologist of New York for 1893.

970. Northern front of Catskills, and Cairo knob, from near Leeds, New York. Catskill creek in the fore and middle ground.

971. Wittemburg range, southern Catskills, from half a mile east of Shokan station, looking west.

972. Esopus shales, on west bank of Esopus creek, two miles above Saugerties, New York. Ledges of Oriskany sandstone are seen along the east bank. Published as a plate in report of state geologist of New York for 1893.

973. Champlain clay lying against Helderberg limestones, west shore of Hudson river, near Rondout, New York; looking north. Published as a plate in report of state geologist of New York for 1893.

974. Quarry in Becraft limestone, Rondout, New York; looking north. Published as a plate in report of state geologist of New York for 1893.

975. Cement beds and limestones on Wallkill Valley railroad, one mile south of Whiteport, New York. Published as a plate in report of state geologist of New York for 1893.

976. Arch in Salina and Clinton beds at High Falls, Ulster county, New York; looking north. Published as a plate in report of state geologist of New York for 1893.
977. High Falls, Ulster county, New York. Over cement beds of the Salina formation. Looking north. Published as a plate in report of state geologist of New York for 1893.
978. Clinton and Salina formations in west bank of Rondout creek at High Falls, Ulster county, New York.
979. Looking southward across lake Mohonk, Ulster county, New York. This lake is surrounded by cliffs of Shawangunk grit. Published as a plate in report of state geologist of New York for 1893, and also in National Geographic Magazine, volume vi, plate 2.
980. Eastern face of Shawangunk mountain, two miles south of lake Mohonk, Ulster county, New York. Shawangunk grit lying on Hudson shales. Published as a plate in report of state geologist of New York for 1893, and also in National Geographic Magazine, volume vi, plate 3.
981. Cliffs of Shawangunk grit on west shore of lake Mohonk, Ulster county, New York. Published as a plate in report of state geologist of New York for 1893.
982. Awosting falls, on the Peterkill, near lake Minnewaska, Ulster county, New York. Over Shawangunk grit. Published as a plate in report of state geologist of New York for 1893.
983. Honk falls, over flaggy beds of Devonian age, near Napanoch, Ulster county, New York; looking north. Published as a plate in report of state geologist of New York for 1893.
984. Marginal conglomerate of Newark formation in railroad cut one mile southwest of Culpepper, Virginia; looking east.
985. Lafayette gravels on Chesapeake sands four miles west of Port Tobacco, Charles county, Maryland; looking north.
986. Earlier Columbian gravels and loam in street cut in western part of Baltimore, Maryland.
987. Clays and sands of Potomac formation overlain by earlier Columbian gravels and sands, penetrated by many sheets of ferruginated materials. In road cut one mile southeast of Anacostia, District of Columbia.
988. Gravel bed and loams of earlier Columbian, on weathered crystalline rocks, in north side of cut of Rock Creek electric railway just east of Rock Creek bridge, Washington, D. C.
989. Earlier Columbian gravel bed and loams on crystalline rocks in cut of electric railway just east of Rock Creek bridge, Washington, D. C.; exhibiting a fault. Looking north.
990. Lafayette gravels and loams lying on Chesapeake sands near northwest entrance of Soldiers Home, Washington, D. C.; looking north.
991. Earlier Columbia gravels three miles southeast of Washington, D. C.
992. Chesapeake sands, Severn clays and Potomac sands in road cut half a mile southwest of Good Hope, District of Columbia. The blade of the hammer is at the Chesapeake-Severn contact, the position of which is also indicated by the arrows to the right. The Severn-Potomac contact is three feet below and is clearly exhibited. The Pomunkey formation is absent.
993. Shell beds in Chesapeake formation on west side of Patuxent river, at Jones' wharf, Saint Marys county, Maryland.

994. Cliffs of Chesapeake sands and clays surmounted by Lafayette gravelly sands, Plum point, Calvert county, Maryland; looking south.
995. Highly fossiliferous Chesapeake sands on shore of York river, half a mile below Yorktown, Virginia; looking southeast.
996. Severn formation on east side of Gibson island, Magothy river, Anne Arundel county, Maryland. Shows characteristic silicious concretions in place and along the shore.
997. Cliffs of Potomac clays, Wortons point, Kent county, Maryland.
998. Ferruginous concretions in sand of Potomac formation in road cuts on Patterson estate, northeastern Baltimore, Maryland.
999. Sands, gravels and clays of Potomac formation in cut of Belt Line railroad, just east of Belair road, northeastern Baltimore, Maryland.

Six (6 x 8) photographs taken by Arthur Keith

1000. Dissected plateau of Blue ridge at head of New river, North Carolina.
1001. Grandfather mountain and Watauga valley, looking west from the Blue ridge, North Carolina.
1002. South side of Grandfather mountain from Yonahlossee road, North Carolina.
1003. Blue ridge and Blowing rock, looking east across the head of Johns river, North Carolina.
1004. West end of Grandfather mountain, showing above Blue ridge, North Carolina.
1005. Conglomerate ledges on Yonahlossee road, south side of Grandfather mountain, North Carolina.

*Sixty-eight* (6 x 8) *Photographs taken and presented by Professor William Libbey, Jr., of the E. M. Museum of Geology and Archæology, Princeton, New Jersey*

Professor Libbey's numbers are given thus (43)

| | | | |
|---|---|---|---|
| 1006 | (43). | Hawaii. | *A.* Hilo bay (see next). |
| 1007 | (49). | " | *B.* Hilo bay, from Cocoanut island; city five miles distinct. |
| 1008 | (58). | " | Peepee falls, near Hilo. |
| 1009 | (59). | " | The "pots," near Hilo. |
| 1010 | (60). | " | Down the gorge from the "pots." |
| 1011 | (57). | " | Rainbow falls, on the Wailuku. |
| 1012 | (61). | " | Aa lava, flow of 1841, near Kapoho. |
| 1013 | (64). | " | Green lake, Kapoho. |
| 1014 | (67). | " | Fissure, Kapoho. |
| 1015 | (71). | " | Pit crater, Puna. |
| 1016 | (70). | " | Lava tree; Mr Lyman. |
| 1017 | (69). | " | Lava trees, Puna. |
| 1018 | (68). | " | Lava trees showing structure, Puna. |
| 1019 | (66). | " | Blue lake, Kapoho. |
| 1020 | (56). | " | Lava stalactites, flow of 1881, Bougainville. |
| 1021 | (46). | " | Mauna Loa from Hilo, 35 miles distant. |
| 1022 | (74). | " | Volcano house, at edge of Kilauea. |
| 1023 | (78). | " | *A.* Panorama of Kilauea from Volcano house. |
| 1024 | (79). | " | *B.* Panorama of Kilauea. |
| 1025 | (80). | " | *C.* Panorama of Kilauea. |
| 1026 | (75). | " | Same as *A* (No. 78), with steam issuing from fissures. |

| | | | |
|---|---|---|---|
| 1027 | (85). | Hawaii. | First fissure. Edge of Kilauea. |
| 1028 | (84). | " | Edge of Kilauea. First land slip. |
| 1029 | (85). | " | Fissure back of sulphur banks. |
| 1030 | (82). | " | Sulphur banks. |
| 1031 | (76). | " | Looking back from lava in crater to Volcano house. |
| 1032 | (77). | " | Waldrous ledge; highest part of edge of Kilauea. |
| 1033 | (86). | " | Keanalsakoi; small crater, 500 feet deep, near Kilauea. |
| 1034 | (87). | " | Flow of 1868, on isthmus between Kilauea and Kilauea isli. Tree in lava. |
| 1035 | (89). | " | Pathway over lava; bridge over fissure. |
| 1036 | (90). | " | Fissure in (No. 89), looking west. |
| 1037 | (91). | " | Fissure, looking east. |
| 1038 | (92). | " | Bubble, Kilauea. |
| 1039 | (94). | " | Bubble, Kilauea. |
| 1040 | (93). | " | Spatter cone, Kilauea. |
| 1041 | (88). | " | Broken crust in lava of Kilauea, showing caves. |
| 1042 | (95). | " | Hut on edge of Halemanman. Destroyed in March, 1894. |
| 1043 | (96). | " | Active portion of Halemanman; 1,000 feet in diameter. |
| 1044 | (97). | " | Surface flow; Halemanman. |
| 1045 | (98). | " | Surface flow; Halemanman. |
| 1046 | (99). | " | Halemanman; lava surface. |
| 1047 | (100). | " | Halemanman; rim of active portion. |
| 1048 | (101). | " | Halemanman; rim of active portion. |
| 1049 | (102). | " | Lava flow from side of active portion. |
| 1050 | (103). | " | Lava flow from active portion. |
| 1051 | (104). | " | Inside the active portion of Halemanman. |
| 1052 | (105). | " | Inside cauldron; Halemanman. |
| 1053 | (12). | Oahu. | Diamond head and Waikiki from Punch Bowl road. |
| 1054 | (15). | " | The Punch bowl from mount Tantalus. |
| 1055 | (2). | " | The Pali road. |
| 1056 | (1). | " | The Pali. |
| 1057 | (3). | " | The Pali cliffs from the road below them on the Kaueohe side. |
| 1058 | (7). | " | Kaueohe valley from Pali road. |
| 1059 | (5). | " | Kaueohe peninsula. |
| 1060 | (106). | Maui. | On the road to Haleakala. |
| 1061 | (108). | " | Summit Haleakala; 10,032 feet. |
| 1062 | (113). | " | Cloud effect on summit of Haleakala. |
| 1063 | (126). | Kauai. | Valley of Kipukai; general view of house and valley. |
| 1064 | (112). | Maui. | Rim of crater to southeast; outside. |
| 1065 | (116). | " | Inside crater of Haleakala. |
| 1066 | (114). | " | On floor of crater of Haleakala; looking to the northeast (highest point). |
| 1067 | (115). | " | On floor of crater of Haleakala. |
| 1068 | (119). | " | Kaupo gap. |
| 1069 | (132). | Kauai. | Valley of Kalihiwai. |
| 1070 | (133). | " | Valley of Haualei. |
| 1071 | (139). | " | Haeua point. |
| 1072 | (140). | " | Haeua point; lava cave at sealevel. |
| 1073 | (141). | " | Haeua point; lava cave 100 feet above sealevel. |

*Presented by the United States Geological Survey, C. D. Walcott, Director*

Twenty-one (10 x 13) photographs taken by J. K. Hillers

1074. Cranberry iron works, North Carolina.
1075. View on the French Broad, North Carolina.
1076. Hickory Nut gap, North Carolina.
1077. Hickory Nut gap, North Carolina.
1078. View on the French Broad, North Carolina.
1079. Hickory Nut gap, North Carolina.
1080. Model farm, North Carolina.
1081. Hickory Nut gap, North Carolina.
1082. Garden of the gods, Colorado.
1083. Big trees, Mariposa, California.
1084. Yosemite Falls cliff, California.
1085. The Sentinel, Yosemite, California.
1086. El Capitan, looking southeast, California.
1087. El Capitan, looking west, Yosemite valley, California.
1088. Washington column, Yosemite valley, California.
1089. Home of the Storm Gods, Yosemite valley, California.
1090. Three Graces, Yosemite valley, California.
1091. Royal Arches, Yosemite, California.
1092. Royal Arches, Yosemite, California.
1093. Home of the Storm Gods, Yosemite, California.
1094. Yosemite valley, California.

On motion of the Secretary, the report of the Committee on Photographs was adopted. The committee was continued with an extension of the annual appropriation of fifteen dollars for the year 1895, and Mr J. S. Diller was, on his own request, relieved from service on the committee and Mr G. P. Merrill was appointed in his place.

The following resolution was offered by W J McGee and unanimously adopted:

Whereas the work of the Committee on Photographs has added materially to the interest of the meetings of the Geological Society of America and has proved a valuable adjunct to the work of the Society, therefore

*Resolved,* That the Society, on the occasion of the retirement of the chairman of the committee, express hereby special appreciation of the valuable services of the Committee on Photographs under the chairmanship of Mr J. S. Diller.

The report of the special committee appointed at the summer meeting to consider the communication of the Royal Society relating to a catalogue of scientific papers was read by H. S. Williams. On motion of C. D. Walcott, the report was accepted and ordered printed. Subsequently W J McGee proposed an addition to one clause of the report, which was referred to the committee, with power to incorporate the amendment if they approved. The committee has duly approved the amendment, and

the full report following is placed before the Society for action at the next meeting.

### *REPORT OF COMMITTEE ON ROYAL SOCIETY CATALOGUE*

*To the Geological Society of America:*

Your committee to whom was referred the communication of the Royal Society relating to a catalogue of scientific papers, to be made by international cooperation, respectfully submits the following report:

The committee finds itself fully in sympathy with the desire of the Royal Society to improve the methods of cataloguing scientific literature, and is distinctly of the opinion that the establishment of such a catalogue, to be compiled through international coöperation, is both desirable and practicable.

To determine in what way this result can be best attained, it will be well to consider what are the defects of existing methods and what are the requirements which an improved system may be reasonably expected to fulfill.

Bibliographic catalogues and indexes are generally defective in one of two ways: Either they present simply a list of titles, which often convey an inadequate and sometimes a misleading idea of the contents of the articles catalogued, or they appear, like the various annual reports, so long after the publication of the articles which are reported upon that they lose a great part of their value as guides to current literature. A third defect is common to all existing catalogues, namely, that of necessitating a reference to a number of separate volumes whenever the literature of several years is sought.

It is evident that some form of card catalogue can alone remedy these defects, so that the practical question is: How can a card catalogue of current scientific literature be best established and maintained? The requirements of such a catalogue may be stated as follows:

1. It should appear promptly; if possible, simultaneously with the book or article catalogued.
2. It should furnish an accurate description of the purport of the book or article.
3. It should be readily accessible to all persons interested in the literature catalogued.

It seems probable that these requirements may best be met by the coöperation of a central bureau with the various publishers and editors of scientifie literature in issuing with each book and with each number of every periodical a set of cards of standard size and type, each card to exhibit for a book or for a single article in a periodical—

1. The name of the author.
2. The title of the book or article.
3. The date, place and house of publication of the book, or the title, volume and page of the periodical in which the article appears.
4. A brief statement, not to exceed eight or ten lines, to be prepared by the author himself, setting forth the general purport of the book or article, so as to furnish the necessary data for cross-references.

Each card should be in duplicate to permit of arrangement according to subject or author, or both if desired, and additional cards should be issued whenever the character of the title necessitates cross-references. A card when printed would present somewhat the following appearance:

DAWSON, J. W. Acadian Geology.

Macmillan & Co., London and New York. 3d ed. 1878. pp. 694+102. 8°.

*Summary* :

SALISBURY, ROLLIN D. Superglacial Drift.

Journal of Geology. 1894. Vol. II, pp. 613–632.

*Summary* :

The dimensions and texture of the card should be determined by careful comparison of the cards already in use in the principal libraries of the world.

Space should be left at the top of the card for writing such words as may be desired for cross-references. This could best be done by each person for himself, as there would necessarily be much difference of opinion as to the number and character of the cross-references desired. Furthermore, subscribers of different nationalities would wish to catalogue the same subject under different headings, as, for example, an article on the spleen would be catalogued by a Frenchman under *rate* and by a German under *Milz.*

If thought desirable, the type used in printing the cards could be kept set up till the end of the year, and then, by arranging the material according to subjects, an annual report in book form could readily be published.

A central bureau charged with the work above outlined could very properly be established under the auspices of the Royal Society. In this central office subscriptions could be received from libraries and individuals for the cards relating to the

articles published in certain journals or to the literature of certain departments of science, and the subscriber would thus receive, in weekly installments, a complete card catalogue of all the literature in his own line of work. The cards thus received could be arranged by each subscriber so as to form the sort of card catalogue best adapted to his own needs.

Although in this scheme the greater part of the work, including the printing of the cards, would be done in a central office, yet the cooperation of the publishers could not well be dispensed with, for from them must be obtained the summaries prepared by the authors, which form an essential feature of the scheme. Little difficulty need be anticipated in obtaining such summaries, for it would be to the interest of the writers to furnish them, and no one could prepare them so easily and correctly as the writers themselves. To facilitate obtaining the summaries it might be well for the central office to invite editors, especially of the publications issued by scientific societies and offices of the more technical scientific periodicals of limited circulation, to have suitable summaries of papers published by them prepared by the authors thereof, such summaries to be put in type and perhaps printed in connection with the articles.

A central office with this function would readily secure the cooperation of libraries and learned societies throughout the world, and to an undertaking thus endorsed the publishers of scientific literature would doubtless lend their aid, since they would find in it a means of advertising their business. The support of such an office could be provided for at the outset by international subscription, but it would doubtless in a short time become self-supporting, since portions of the total catalogue would be needed not only in every public library, but on the study-table of every serious student in every department of science.

The above report is submitted not as an elaborated plan, but as a suggestion of the end to which effort should be directed. Your committee would further express the hope that some plan may be put into operation at an earlier date than the year 1900, the time suggested in the circular of the Royal Society.

In accordance with the views above set forth the committee respectfully recommends the adoption by the Society of the following:

1. That, in the opinion of the Geological Society of America, the establishment of a catalogue of scientific literature to be maintained through international coöperation is both desirable and practicable.

2. That a copy of this report be transmitted to the Royal Society as a suggestion of the way in which this plan may be best carried out.

3. That the Society be requested to contribute a suitable sum toward the carrying out of this enterprise, provided the plan finally adopted by the Royal Society shall appear to the Council of the Society to be practicable.

N. S. Shaler,
Henry S. Williams,
W J McGee,
*Committee.*

The reading of scientific papers was declared in order, and a ruling of the Council was announced that for papers which bore no time-limit in the printed program only fifteen minutes should be allowed for each paper, and that a limit in discussion to five minutes for each speaker should be enforced.

The first paper of the session was—

### *OBSERVATIONS ON THE GLACIAL PHENOMENA OF NEWFOUNDLAND, LABRADOR AND SOUTHERN GREENLAND*

BY G. FREDERICK WRIGHT

Remarks were made by C. D. Walcott. The paper is published in the American Journal of Science, volume xlix, pages 86–94.

The second paper was as follows:

### *HIGH-LEVEL GRAVELS IN NEW ENGLAND*

BY C. H. HITCHCOCK

[*Abstract*]

The object of this paper is to announce the discovery of glacial lakes in the hydrographic basin of lake Memphremagog and adjacent regions, reserving the presentation of details to a later date. This lake is 695 feet above the ocean. The best defined strands are found about the head of the lake in and near Newport, Vermont; in the valleys of Clyde river; Barton river, along the Passumpsic railroad, and Black river as far as Craftsbury. These localities are all in Vermont. In Quebec these levels appear at the south base of Owls Head, in Stanstead and on Bunker hill. The levels seem to lie approximately at 970, 1,060 and 1,270 feet above the ocean. The lowest is the most distinct. The highest is developed two or three miles northeasterly from Stanstead plain. The drainage is entirely to the north, and the material may have been washed from a terminal moraine of the great ice-sheet, shown by me to extend probably from the Androscoggin lakes, in northwestern Maine, across New Hampshire and Vermont to the mouth of the La Moille river on lake Champlain. In 1861 I described a beach near Fort Kent, in northern Maine, which seems to have about the same level as the lowest of the Memphremagog strands. I have lately observed with attention a well defined level of 1,500 feet above the ocean near the Twin Mountain house, in Carroll, New Hampshire, in the edge of the White Mountain district. It seems to have been another beach-line of a body of glacial water covering the valley of Israels river, a tributary of the Connecticut. In case the present drainage of the Connecticut were obstructed at Fifteen Mile falls and the summit of the Concord and Montreal railroad at Whitefield, the outlet of this lake would have been tributary to the Androscoggin at Gorham, New Hampshire. The col separating this last named Jefferson lake from the earlier Memphremagog lake along the Passumpsic railroad near Barton, Vermont, is about 150 feet lower than the abandoned strand at the Twin Mountain house.

Remarks were made by J. W. Spencer, as follows:

While I fully appreciate the data collected and views presented by Professor Hitchcock, I cannot accept his conclusions concerning the barriers of ice which he hypothecates for the retention of the water at the levels of the terraces. On a former occasion I presented to this Society reasons of a physical nature why I could

not accept the glacial-dam hypothesis. Now I am able to give geomorphic data in support of my position in setting aside the necessity of glacial dams. I have found on the western, southern and eastern sides of the New England mountain masses the same terraces as those on the northern, without other variation than such as arose from the changing topography. The terraces of the great valleys are not those of rivers, but approach the levels of plains, and in the descent from the higher to the lower country they do not slope outward and down the valleys as river terraces, but descend abruptly as steps, from a few to 200 feet or more in height, of the same character on all sides of the mountains. The terrace plains at substantially the same levels extend down the valleys for miles before terminating in the abrupt steps. The materials came primarily from the drift, but that of the lower terraces came chiefly from the erosion of those above. The materials thin out as the valleys become larger and broader and farther from the sources of supply; and, furthermore, as the rivers keep cutting deeper and deeper and leaving the terraces higher above them the erosion is so increased that the terrace materials do not commonly extend from one great valley to another. I conclude that the terrace plains were formed at sealevel, and that the mountain region has been raised as much as the sum of the heights of the terrace steps, or more than 2,000 feet since the Glacial period, but that the coastal region need not have been depressed to the maximum depth, for it has been observed in the southern mountains and in the West Indies that during the last epeirogenic movements the mountain regions have been raised to a greater extent than the coastal plains.

A proposition to relieve the very extensive program of the meeting by the creation of a temporary petrographic section where the several technical papers in petrology and mineralogy should be read was voted. The proceedings of that section will be found on page 469.

The next paper in the main section was—

### *VARIATIONS OF GLACIERS*

BY H. F. REID

[*Abstract*]

Great interest has been aroused lately in the study of the variations of glaciers. Observations on the glaciers of the Alps have shown that variations in their dimensions undergo a periodic change; that they increase, attain a maximum, decrease, reach a minimum, and then begin to advance again two or three times in a century. Records of more or less exactness extend back two or three hundred years. Glaciers, however, are not all in the same phase at the same time; indeed, some begin to advance when others have almost reached their maximum. Glaciers side by side are sometimes found in opposite phases. This makes it so difficult to find the relation between the variations of climate and of glaciers. Some progress has, however, been made in this direction. The theories of Richter and of Forel, advanced to account for the curious behavior of glaciers, were explained. Accurate information is wanted on the changes which glaciers undergo. The International Congress of Geologists at Zurich last summer appointed a committee to collect information on the variations in glaciers all over the world. The rest of the paper

gives methods of observing and recording the extent of glaciers. The paper was presented with the hope of enlisting the help of such members of the Society as may have the opportunity to make observations on American glaciers.

The paper will be published in the Journal of Geology.

The following two papers by the same author were read in succession and discussed together:

### *DISCRIMINATION OF GLACIAL ACCUMULATION AND INVASION*

BY WARREN UPHAM

This paper is printed as pages 343–352 of this volume.

### *CLIMATIC CONDITIONS SHOWN BY NORTH AMERICAN INTERGLACIAL DEPOSITS*

BY WARREN UPHAM

This paper, which was discussed by J. W. Spencer, H. F. Reid, R. D. Salisbury and T. C. Chamberlin, is published in full in the American Geologist, vol. xv, May, 1895, pages 273–295, with map.

The next two papers were read together and discussed as one:

### *GLACIAL LAKES OF WESTERN NEW YORK*

BY H. L. FAIRCHILD

This paper is printed as pages 353–374 of this volume.

### *LAKE NEWBERRY THE PROBABLE SUCCESSOR OF LAKE WARREN*

BY H. L. FAIRCHILD

[*Abstract*]

The widely expanded waters of lake Warren, with its outlet at Chicago to the Mississippi, laved the front of the receding ice-sheet as the latter slowly uncovered western New York. The surface of at least the western part of this area bears many evidences of postglacial flooding up to a height of nearly 900 feet, and beaches of the Warren waters have been traced about lake Erie, the lowest with an altitude at Crittenden and Alden, New York, east of Buffalo, of 860 or 864 feet above tide. When the ice had retreated so far as to uncover the valley of the Mohawk river, a much lower outlet to the Hudson was found by the glacial waters and they fell to the level of lake Iroquois, which has left distinct beaches about the Ontario basin. The shore inscriptions of lake Warren as far eastward as Crittenden, New York,

and the clear records of lake Iroquois have been ably discussed by Fellows of this Society.* The lacustrine phenomena involved in the expansion of the ice-dammed waters over western-central New York and their subsidence from the Warren to the Iroquois levels have not been described. However, in the long interval of time required for the edge of the ice-barrier to sweep across the extent of about 200 miles lies an unwritten history to which this and the preceding paper are an introduction.

This paper suggests the possibility of a southward outlet for the vast glacial waters intermediate in time and elevation between the Chicago and the Rome outlets. Between these two old outlets the lowest pass with present topography is the former outlet of the Western Erie glacial lake near Fort Wayne, Indiana, which is now 770 feet above the sea, being about 180 feet above the Chicago outlet, but at the time of its efficiency it was only about 30 feet above that outlet. The next lowest pass, and the one under consideration, is the outlet south of Seneca lake, where the considerable water of the Watkins glacial lake had early excavated a channel over the col at Horseheads, near Elmira, with a present altitude of 900 feet.† The depression of the Finger Lakes region was so great that it is believed possible that the Horseheads channel was lower than the Chicago channel, which is regarded as having at that time approximately its present altitude.

For this hypothetical stage of the ice-dammed water at the level of the early Watkins lake the name "lake Newberry" is proposed.

The Watkins glacial lake should properly be restricted in name to the area of the Seneca valley. The more expanded lake, which probably united for a time the waters of the Cayuga valley upon the east and the Keuka and Canandaigua valleys upon the west, has already been distinguished by a separate appellation as lake Newberry (see reference above), and these coalescent waters at the Horseheads level should perpetuate the name lake Newberry, even though it should eventually appear that this level was somewhat higher than the Warren waters.

Assuming that no low pass to Hudson bay was uncovered by the glacier during the interval under consideration, then lake Warren must surely have spread its flood over all the area of western New York north of the present divide between the Saint Lawrence and the Susquehanna-Ohio waters up to a height determined by the relation of its outlet to the altitude of the Ontario basin. Whether the Horseheads channel was then low enough to rob the Chicago outlet of the Warren waters is a problem involving the amount of differential depression in southern-central New York. The character and capacity of the Horseheads channel is another element in the discussion.‡ At this time, with a want of evidence, the suggestion is presented, in an argumentative form only, as an hypothesis to be tested by future investigations. The data are given in abstract. The figures relating to former elevations or changes of altitude are, of course, not absolute. For most of these data the author is indebted, through publications or correspondence, to the several authors named above.

* The writings of Messrs Warren Upham, J. W. Spencer, G. K. Gilbert and Frank Leverett upon the glacial lakes are so well known to geologists that it is not deemed necessary to give specific references in this abstract. These writings are found in this Bulletin, and especially in recent volumes of the American Journal of Science and the American Naturalist. A succinct review of the extinct lakes in the Saint Lawrence basin is given by Warren Upham in the American Journal of Science, vol. xlix, January, 1895, pp. 1-18, with extended bibliography.

† See pages 365-369 of this volume.

‡ This volume, pp. 366-369.

*Comparison of Elevations*

| | Present altitude above tide. | Former altitude above tide. | Change in altitude. |
|---|---|---|---|
| | *Feet.* | *Feet.* | *Feet.* |
| Lake Ontario | 247 | ............ | ............ |
| Cayuga lake | 378 | ............ | ............ |
| Seneca lake | 440 | ............ | ............ |
| Rome outlet of lake Iroquois | 440 | 50–100 | 340–390 |
| Chicago outlet of lake Warren | 590 | 590+ | ............ |
| Beach at Crittenden, New York | 860 | 590 | 270± |
| Horseheads channel | 900 | (?) | (?) |

| | *Difference in altitude.* |
|---|---|
| Between Horseheads and Chicago channels | 310 feet. |
| Between Crittenden beach and earliest and lowest Iroquois beach | 635 " |
| From this Mr Upham deducts 100 feet as allowance for progressing uplift, giving as an estimate of fall in water surface between lakes Warren and Iroquois | 535 " |

*Differentials of Elevations.*

Crittenden beach, from Toledo, Ohio, to Crittenden, New York, 9 inches per mile, east-northeast.

Iroquois beach, from meridian of Crittenden to meridian of Rochester, 9 inches per mile, east.

Iroquois beach, from Rochester to Rome, practically level, east and west.

Iroquois plane, from Weedsport to Richland, 3 feet per mile, northeast by north.

Most of the glacialists who are working upon the extinct lakes are of opinion that the earliest Iroquois beaches were formed not far above sealevel. With no north-and-south differential elevation, the Horseheads col would then be carried far under the Chicago outlet, but there is evidently considerable north-and-south differential in the region immediately north of the Finger lakes; consequently just here is the real quantitative problem, which cannot be solved until much careful work has been done upon the shore phenomena of the glacial Watkins and Ithaca lakes.

Mr Gilbert thinks that the earliest Iroquois plane passes beneath the surface of Cayuga lake not farther south than the middle of the lake, and with an inclination of perhaps 3 feet per mile. Assuming the subsidence from the Warren level to the Iroquois level as 535 feet, then 378 feet, the present altitude of the Iroquois plane where it cuts the surface of Cayuga lake, would have been in early Iroquois time 323 feet lower (378 — (590–535) = 323), but Horseheads is 35 miles farther south, and continuing the Iroquois plane with the same inclination would allow the Horseheads channel a depression of only 218 feet. A depression of 310 feet was necessary to make it drain the Warren waters.

The above calculation illustrates the negative argument; but even if that result be established, it will not be conclusive. The episode of lake Iroquois, with the alti-

tude of the Ontario basin from 340 to 390 feet lower than now, was long subsequent to the invasion of the Seneca valley by the Warren waters. The duration subsequent to this invasion, while the Mohawk valley was yet ice-buried, but while the area of the Finger lakes was relieved of its ice-burden, would probably have allowed the latter area to recover somewhat from its depression.* The relation of the subsequent Iroquois plane to the earlier lifted area would not therefore indicate that previous uplifting. Only 100 feet of earlier elevation would be required, according to the calculation above, to make the channel an outlet for Warren waters.

Another reason for believing in the probability of considerable depression in the Seneca-Cayuga region is the pronounced convexity or lobing of the watershed and of the frontal moraine (see plate 18 of this volume). This lobing of the ice-front, probably due to the great depth of the valleys and massing of the ice, produced a local accumulation of weight which may possibly have caused an exceptionally great local depression.

The Horseheads channel is described in the former paper (pages 366–369). Concerning the smaller breadth of the channel compared with those of the Chicago and the Rome outlets, it may be said that, at the longest, lake Newberry had a relatively short existence. However, between the higher flood-plains the channel is quite a mile broad.

In all the local lake basins, so far as observed by the writer, the heaviest delta terraces are at the summits of the deltas, corresponding to the local outlets, and not at the supposed plane of lake Newberry. The absence of extremely heavy delta accumulations at the supposed proper level suggests several replies:

First. The size of a delta depends not at all upon the size of the receiving water body, but upon the volume of detritus borne in by the stream, multiplied by the length of time. The unprotected drift left by the ice-sheet was accumulated in deltas very rapidly by the earliest streams. As the lake level fell the streams simply bisected their deltas and contributed to lower levels only the regular, reduced supply.

Second. The local lakes had a steadier level and more uniform conditions than the continental lakes, with their vast areas and differential movements of outlets and distant shores; and the duration of some of the local glacial lakes was considerable.

Third. In the case of the non-existence of lake Newberry, then the shore inscriptions of the Warren waters must be found in all the valleys of central New York at a present elevation not far below 900 feet, unless there was, as mentioned above, some unsuspected outlet. However, there seems to be, so far as observation now extends, no good evidence of a general water-level below 900 feet, while from Batavia eastward the lower terraces of stream deltas do suggest a general water-plane near or above 900 feet.

Fourth. Similar absence of shore-markings is frequent about the shores of the great glacial lakes.

> "Most of the northern beaches (of lake Warren), it should be remarked, are very feebly developed, even in the most favorable situations for their formations, and are not discernible along the far greater part of the lake borders." †

The writer suggests the possibility, as helping to explain the want of strong shore phenomena, that lake Newberry may have had a brief and precarious existence,

* Warren Upham: Wave-like progress of an epeirogenic uplift. Journal of Geology, vol. ii, pp. 383–395.

† Warren Upham: Am. Jour. Sci., January, 1895, p. 7.

and that then the rise of the region, including the outlet at Horseheads, may have thrown the overflow back upon the Chicago outlet.

The two papers were discussed by several Fellows:

Mr Gilbert spoke in confirmation of the matter of the first paper. From personal observation he could affirm that south of several cols described in the paper there were abandoned stream channels showing their peculiar and unmistakable characters. He commended the name given in the second paper as a richly deserved tribute to the great services of Professor Newberry in glacial geology, but had some doubt concerning the character and capacity of the Horseheads channel.

Mr McGee referred to the importance of Dr Newberry's work and influence in the early study of glaciology in America, and thought the choice of the name both timely and felicitous.

Mr Upham suggested that the "Newberry" level might correlate with Dr Spencer's Lundy beach; the differential of uplift, measuring from the Iroquois level, seemed to nearly correspond.

Mr Spencer said that his objections to the glacial dams had been referred to in his remarks upon the paper of Professor Hitchcock. In the locality of Professor Fairchild's work he had observed terraces 300 feet above the Horseheads plain which could not have heen held in by a glacial dam unless such were upon the southern side of the drainage. So also on the southern side of the Adirondacks there were terraces to at least 600 feet above the depression in the country to the south. Until these can be explained by glacial dams there is no reason for invoking the same for the terraces facing the north; also the deltas below the divide represent waters draining to the north, yet between the different valleys they have not been connected, and if their drainage was back into the ice, then it would be necessary to find some kind of ice which would not be melted by water draining through it and lowering the later levels.

With regard to the successor of Warren water being named Newberry, Mr Spencer had only the objection to urge that it had been already named for the Erie-Ontario valley, the Lundy lake, and for the Huron valley, the Algonquin lake or water, and that for hundreds of miles these deserted lakes had been surveyed. He referred to one other fact, namely, that the Forest beach or the last stage of Warren water had never emptied by way of Chicago, but there was no reason why the water-line might not have extended to the head of Seneca valley, as suggested by Professor Fairchild. However, near Batavia, where Dr Spencer had examined some gravel deposits which he had supposed might represent the Forest beach, he found the material of such a character that he could not correlate it with the typical beach. He was very glad that these beaches had enlisted the interest of Professor Fairchild, whose work will be a valuable addition to this most interesting study of dynamic geology; but while differences of theory give enthusiasm to the investigation and elicit new facts, in the end they will settle the disputed questions, and then there will be little interest in the completed work beyond the catalogue of dry data.

Professor W. B. Clark announced that the Fellows were invited by the Local Committee to a luncheon in the University gymnasium, and the Society adjourned for the midday recess.

At 2 o'clock p m the Society was again called to order, and the President read the following paper:

### *NOTES ON THE GLACIATION OF NEWFOUNDLAND*

BY T. C. CHAMBERLIN

[*Abstract*]

Attention was called to the geologic structure of the Avalon peninsula of south-eastern Newfoundland as affording peculiar facilities for determining the direction and extent of drift transportation. The center of the peninsula is occupied by crystalline rocks, referred by Murray and Howley to the Laurentian age, surrounded concentrically by schistose series overlaid by red sandstone. The glacial striæ on the eastern side of the peninsula indicate a movement eastward. Those on the northwestern border indicate a northwesterly movement toward Concepcion bay. Striæ were found on the westward side, indicating a western movement toward Placentia bay. An accumulation of kames and moraines on the isthmus between Placentia and Trinity bays suggests a westerly movement from the heart of the Avalon peninsula. The inference was therefore drawn that the peninsula was formerly covered by an independent ice-cap whose borders moved outward in all directions.

In the vicinity of Saint Johns and Petty harbor a belt of red sandstone occupies the coast. Bordering this on the inland side is a tract of schists and semicrystalline rocks of prevailing dark and gray colors, rendering them readily distinguishable from the red sandstone. Back of these, in the interior, lies a nucleus of the granitic or gneissic type. Along the coast the erratics are nearly all of the local red sandstone. Only a few of the gray crystalline rocks mingle with them. Going westward toward the junction of the two formations, the gray crystalline rocks come in with great rapidity and soon replace the red sandstone. It is a singular fact, however, that no granitic erratics from the interior nucleus, or at most extremely few, mingle with either of these classes near the coast. These facts indicate an extremely local derivation and a very short transportion of the drift.

So far as data were gathered relative to the interior of Newfoundland, from the observations of government geologist Howley and the late Alexander Murray, and from personal observations, the impression was gained that the glaciation of the island was more probably attributable to development of local ice-sheets than to an extension of the ice fields of the mainland.

Remarks were made upon the paper by Warren Upham and C. H. Hitchcock.

In the absence of the author the following paper was read by Mr Upham:

### *THE PRE-CAMBRIAN FLOOR IN THE NORTHWESTERN STATES*

BY C. W. HALL

Remarks were made by G. K. Gilbert.

The following three papers were read in immediate succession and discussed as a whole:

*A FURTHER CONTRIBUTION TO OUR KNOWLEDGE OF THE LAURENTIAN*

BY FRANK D. ADAMS

*CRYSTALLINE LIMESTONES, OPHICALCITES AND ASSOCIATED SCHISTS OF THE EASTERN ADIRONDACKS*

BY J. F. KEMP

This paper is printed as pages 241–262 of this volume.

Mr Gilbert was requested to occupy the chair, and there was then read the third paper:

*CRYSTALLINE LIMESTONES AND ASSOCIATED ROCKS OF THE NORTHWESTERN ADIRONDACK REGION*

BY C. H. SMYTH, JR.

This paper is printed as pages 263–284 of this volume.

The three papers were discussed by Whitman Cross, J. E. Wolff, C. D. Walcott and the authors.

The next paper was presented by the author in a few words:

*LOWER CAMBRIAN ROCKS IN EASTERN CALIFORNIA*

BY CHARLES D. WALCOTT

This paper is published in the American Journal of Science, volume xlix, February, 1895, pages 141–144.

The paper following was—

*DEVONIAN FOSSILS IN CARBONIFEROUS STRATA*

BY H. S. WILLIAMS

Remarks were made by Jed Hotchkiss.

The following paper was then read:

*THE POTTSVILLE SERIES ALONG NEW RIVER, WEST VIRGINIA*

BY DAVID WHITE

This paper was discussed at length by I. C. White, Jed Hotchkiss, C. D. Walcott, H. S. Williams and M. R. Campbell. It is printed as pages 305–320 of this volume.

Mr Gilbert requested Mr Walcott to occupy the chair, and he presented the last paper of the day in the main section:

### *SEDIMENTARY MEASUREMENT OF CRETACEOUS TIME*

BY G. K. GILBERT

The paper is published in the Journal of Geology, volume iii, 1895, pages 121–127.

### *ORGANIZATION OF THE TEMPORARY PETROGRAPHIC SECTION*

This division of the Society met at 11.30 o'clock a m in the "Williams room" of the geological building. Professor B. K. Emerson was made chairman and Mr Whitman Cross secretary. The first paper read was—

### *THE RELATION OF GRAIN TO DISTANCE FROM MARGIN IN CERTAIN ROCKS*

BY ALFRED C. LANE

The paper elicited discussion, in which the chairman and E. O. Hovey, J. F. Kemp, J. P. Iddings, G. P. Merrill, F. D. Adams and Whitman Cross participated.

The second paper was by the same author:

### *CRYSTALLIZED SLAGS FROM COPPER SMELTING*

BY ALFRED C. LANE

[*Abstract*]

The specimens of slags exhibited are from the smelting works at Dollar bay, and on Torch lake, in the copper country of upper Michigan. The copper as it comes from the mines, if not in masses suitable to be directly smelted into bars, is stamped and washed, and the resulting concentrates or "mineral" is melted into ingots. Most of the copper is found native, therefore, and remains so, but in the process of melting down a small part is oxidized. The waste and scraps of the direct process must therefore be reduced in a cupola furnace. Kelly Island limestone from lake Erie is used as a flux with the coal. It has been the custom at times to let the slag from the cupola furnace run into hemispherical iron pots, which are two feet in inner diameter and one foot deep and mounted on a carriage. The slag is then allowed to cool naturally and the solid contents dumped. In the interior of these pots, within the crust formed by the first cooling, cavities formed, and from these came some of the crystals exhibited. These slags show in general a strong tendency to be crystalline, and are very often devitrified to within two centimeters from the outer surface.

1. The most interesting crystals are the very large ones of melilite, one or two centimeters square and up to one centimeter thick. The general form is that of square tablets, but the faces are rounded, exactly as if they were on the point of being

remelted and in a viscous condition. Carefully examined, they show a reticulated surface. A partial analysis by Professor R. L. Packard gave—

| | | | |
|---|---|---|---|
| $SiO_2$ | 34.84 | per | cent. |
| $Fe_2O_3$ | 16.78 | " | " |
| $Al_2O_3$ (by difference from 30.04 per cent sesquioxides) | 13.26 | " | " |
| Bases CaO, MgO, etcetera (by difference) | 35.12 | " | " |
| | 100.00 | " | " |

Not much stress can be laid on this analysis, as the crystals prove to be merely a shell with a rectangular network of enclosed matter. These ramifying tubes are in places full of greenish birefractive matter. In patches iron oxides have separated out. There are also occasional globules of copper. A basal section of one of these large crystals shows in convergent light a uniaxial cross, very vague even in a thick microsection, thus indicating a low birefraction. The clearer parts of the melilite substance, which run like needles through the inclosed mass, are not parallel to the side faces, but to a prism of the second order.

2. These crystals pass gradually into others of the type commonly hitherto observed in slags, in which the melilite has been more successful in disentangling itself. We see that the previously mentioned larger crystals are in the nature of poikilitic patches, bounded by cavities, the rounding of whose faces is not due to remelting, but to inability of the melilite to mould into its form the whole inclosed mass and completely master the drop-forming tendency of surface tension.

The bright reflecting crystals are piled up in thin tablets, something like tridymite, but in form bounded by faces at right angles to the basal plane and each other. Their angle is rarely truncated by a small prism of the second order. Goniometric observations confirm the tetragonal character of the mineral.

A random section of the devitrified slag shows globules of copper, magnetite or iron growth forms and melilite. The latter is negative, uniaxial, with a refractive index about 1.6, and birefraction varying from 0.008 to 0.020 decreasing toward the center.

These specimens are quite suggestive of the state a rock is in when the poikilitic texture and lava stalactites were formed. The variable and rather high birefraction of this melilite match very well the facts encountered by C. H. Smyth, Jr.*

3. Another interesting occurrence is of small scales of hematite lining a hollow. They stand generally with their breadth perpendicular to the surface of cooling, and hence lend to the surface a bloom like that which gives its name to grape ore, and is produced by the same cause. Frequently a scale is found out of place, lying flat to the surface. They are but a couple of millimeters or so in diameter and very thin.

The next paper was entitled—

*NOMENCLATURE OF THE FINE GRAINED SILICIOUS ROCKS*

BY LEON S. GRISWOLD

Mr Griswold's paper provoked an interesting discussion, in which J. E. Wolff, B. K. Emerson and A. C. Lane took part.

*Am. Jour. Sci., August, 1893, p. 104.

The next paper was read, in the absence of the author, by F. D. Adams:

*SOME DIKES CONTAINING "HURONITE"*

BY ALFRED E. BARLOW

The following paper was presented by the author, who was introduced to the Society by W. B. Clark:

## *THE GRANITES OF PIKES PEAK, COLORADO*

BY EDWARD B. MATHEWS

*Contents*



### Aim of the Paper

It is the aim of this paper to emphasize and corroborate the views held that a large magma may show variations in structure and composition, and that these variations may be made evident by a series of almost contemporaneous eruptions of matter each part of which cuts through the previously formed portions.

The particular feature in this general aim is to give an illustration of such a varying mass in which all of the facies belong to the same closely defined rock-type, all of the variations being in the size of the grain and the character of the texture.

### Area of Occurrence, Age and Composition of the Granites

The rocks which form the basis of this discussion are granites from the Pikes Peak district, collected during the last two (1893–'94) field seasons. The area covered is a little over 900 square miles, situated at and including the "en echelon" ending of the Rampart or Colorado range, along the divide between the Platte and the Arkansas rivers.

The age of these granites is Algonkian, as is evident from their included masses of schist and quartzites, whose sedimentary origin will be discussed in a forthcoming report by Whitman Cross.

Mineralogically they are invariably composed of quartz, microcline and biotite, to which are added occasionally apatite, zircon, fluorite, hornblende, epidote and

allanite. The rock, then, is the granitite of Rosenbusch, the biotite-granite of Zirkel, and the true granite of Michel-Levy.

## Types

### *NUMBER AND GROUPING*

Sixteen different types were separated in the field, which later study shows may be collected into four groups, each of which will be described in a few words.

### *PIKES PEAK TYPE*

This variety is light grayish pink, weathering into bowlders or surfaces covered by a hard silicious coating similar to "desert-varnish." The grain is medium to coarse, the size of the individuals varying from several inches in length, in the porphyritic variety from Raspberry mountain, to a quarter or half an inch in the even grained masses typical of the entire area. In this we have a granite of coarse individuals varying from a perfectly isomerous mixture to the distinctly porphyritic, in which the phenocrysts may reach the length of six inches or more.

### *SUMMIT TYPE*

This variety is confined almost exclusively to the Peak proper and its immediate surroundings, though locally present in other areas. Its color is variably reddish, purplish to light gray. When fresh it usually has a pinkish white tone, but when weathered the rock presents a silver gray groundmass in which are outlined grayish white feldspar phenocrysts.

### *CRIPPLE CREEK TYPE*

This granite varies in color from a grayish white to a dark, almost black tone, though its usual character is a bright though not brilliant red. The grain is medium to fine, the texture saccharoidal-panidiomorphic. This latter results from the character of the microcline, which occurs in rather short, chunky, twinned individuals whose terminations are less clearly defined than the pinacoidal faces parallel to $c'$.

### *FINE GRAINED TYPE*

This type is an isomerous, fine grained, granular rock in which none of the constituents show a tendency toward a porphyritic development

## Genetic Sequence

After the solidification of the main mass (made up of the Pikes Peak type), how long we do not know, it was rent, especially in the area of the present peak, by fissures which were filled immediately by a granite which crystallized into a fine grained porphyritic rock of two varieties (Summit type), the one having phenocrysts which still retain a fresh almost glassy appearance, the other finer grained and bearing smaller more or less opaque feldspar phenocrysts. As the last product in the formation of this granite mass, its newly formed fine fissures were filled by a fine grained red granite. This granitic injection was accompanied sometimes by a development of quartz-feldspar pegmatitic veins.

When the last feature in the formation of the entire granitic mass took place we do not know. There must have been, however, a considerable lapse of time be-

tween the formation of the main mass and the injection of this last variety, for we find this fine red granite widely scattered over the entire area, and we find it to be more recent than the development of "augen" in the coarser mass. Though later, it must have assumed its place long prior to the advent of Paleozoic time, since it occurs much metamorphosed under the unchanged sediments of the Silurian and possibly the Cambrian.

### Conclusions

We find, then, in this area good illustrations of coarse and fine grained granular, hypidiomorphic granular, porphyritic granular to porphyritic micrographitic and panidiomorphic granular structures, each of which characterizes a sharply defined type of a single cycle in which we find but one mineralogic type developed. Besides, should we consider secondary structures we should find all of the variations in the development of "augen" and of gneisses, as well as many of the peculiar features produced in rock masses by the action of hot-spring and mineralizing agencies.

Mr Mathews' paper was discussed by J. P. Iddings, J. E. Wolff, Whitman Cross and H. W. Turner.

The chairman of the section presented the following, with exhibition of the specimens:

## *ILLUSTRATIONS OF PECULIAR MINERAL TRANSFORMATIONS*

BY B. K. EMERSON

*Contents*



### Serpentine Pseudomorphs after Olivine, formerly called Quartz Pseudomorphs

A specimen, presumably unique, was shown, having several large attached crystals more than an inch long, showing the common forms of olivine now changed into a pale yellow serpentine, closely resembling the Snarum forms. The crystals have long been cited as quartz pseudomorphs from Middlefield, but the locality has been lost for many years. This specimen is from the collection of Mr James Clark, formerly of Brooklyn, and now belongs to Smith College. Its label states that the locality was on the brook which crosses the great serpentine bed in Middlefield, and that it was purposely covered up by some one many years ago.

### Calcite Pseudomorphs after salt in Triassic Shale

A specimen of fine black shale of Triassic age is covered with white lines arranged in triangles, crosses and lines, radiating from the corners of small squares. A feathery outgrowth at times borders these lines. The material is calcite, and the lines are tracings of the various chance cross-sections of skeleton cubes, about

an inch in diameter, presumably of salt, replaced by calcite. The extreme delicacy of the forms, the feathery outgrowths and the lack of broken specimens, indicate that they were formed in place in the soft mud. They were, I think, discovered by Mr B. Hosford, of Springfield, and were much studied by him. They have been called chiastolite, and are cited as spinel in Dana's Manual, 1892. The specimen shown was a bowlder from Holyoke. Mr Hosford's specimens were from West Springfield.

### Puckering of Corundum Crystals around Allanite

The well known asbestus mine in Pelham, Massachusetts, is opened on a great dike of black olivine-enstatite rock enclosed in gneiss. The metamorphism which changed the Cambrian conglomerate into gneiss changed the olivine rock, along a network of fissures, into anthophyllite, arranged in transverse fibers, meeting in a suture—a macroscopic olivine network.

A macroscopic "reaction rim" was produced between the two rocks by the interaction of the very basic and the very acid members. Against the olivine rock is a broad band, characterized by very basic minerals—thick bands of biotite, containing apatite, and fine large corundum crystals. Then comes anorthite full of orthite, rutile and tourmaline in large masses. Then the anorthite graduates into andesite, and this, by the gradual appearance of quartz, microcline and biotite, into the common, well bedded gneiss.

A crystal of corundum was shown—largely fine blue sapphire, in which was a crystal of allanite a half inch across, which had coerced the corundum into a fine radiated puckering nearly an inch wide, outside of which the fine cleavage of the corundum assorted itself. The same puckering surrounds the allanite in the massive anorthite.

The section took a recess until 2.15 o'clock p m, at which hour a further adjournment was taken until 4.30. At the latter hour the section reconvened and the following paper was read:

## *SPHERULITIC VOLCANICS AT NORTH HAVEN, MAINE*

BY W. S. BAYLEY

It is not my intention to discuss the subject of spherulites or of the occurrence of volcanic rocks on the coast of Maine. I desire simply to call attention to the existence of large thicknesses of genuine volcanic products, in all probability of Paleozoic age, in the neighborhood of the village of North Haven and in the northern portion of Vinal Haven island, just west of Penobscot bay.

The late Dr Williams announced the discovery of these rocks in a recent number of the Journal of Geology.* They are found not only in the vicinity of the island referred to, but the same or perhaps other areas of them extend eastwardly as far as Little Deer island, on the west side of Penobscot bay.

Mr W. W. Dodge, of Cambridge, Massachusetts, first called my attention to them, and kindly presented me with a few specimens; later Mr Pirsson loaned me some thin-sections cut from rocks on Vinal Haven; so that the discovery of this interesting series of volcanics is due primarily to Messrs Dodge and

* Vol. ii, p. 23.

Pirsson. Having become interested in the specimens sent me by these gentlemen, a three days' visit was made to North Haven, and from this point as a center a few trips were made by water along the neighboring creeks and inlets, and a large number of specimens were collected.

Of course, in the short time at my disposal, I could do little more than note the characteristics of the varieties of rocks observed. Their relations to the surrounding Paleozoic sediments were not investigated, nor was their areal distribution mapped. Enough, however, was seen to convince me that a great quantity of old lavas and tuffs had been spread out over the region in early geological time.

The rocks occur, so far as was determined, mainly in sheets which are nearly horizontal. They comprise dense and porphyritic, dark basaltic looking rocks, amygdaloids, light and dark tuffs, breccias, conglomerates and spherulitic ancient glasses. These beds are cut by diabase and basaltic dikes, whose composition in some instances is like that of some of the beds.

Many of the rocks have been so completely altered that their original composition can no longer be determined. They consist now of quartz, chalcedony, calcite and occasionally other secondary minerals, so aggregated, however, that they often preserve the original rock structure. From this we learn that some of the lavas were basalts; others were probably rhyolites. Some of the former were porphyritic; the latter were usually glassy. In the porphyrites the plagioclase crystals are still preserved, and these are arranged as in the modern andesites. Sometimes the decomposition products of olivine may be detected in them, so that we may safely regard these porphyrites as basic flows.

The tuffs associated with the more basic rocks present all the structural features of recent tuffs. Although they have lost their original composition, their structure can still be recognized as typically tuffaceous.

Amygdaloids are quite common, especially west of North Haven, on the shore. Their amygdules are now filled with calcite and other secondary minerals, and indeed the rock mass is usually completely altered. There can be no doubt, however, that the rocks are true amygdaloidal flows. At their contacts with other rocks the amygdules are large, and away from the contact walls the beds are not infrequently quite free from all traces of the amygdaloidal structure.

As for the rhyolites, we have little on which to base an argument as to their original condition. Many of them present in the weathered surfaces beautiful examples of flowage lines, sometimes forming a series of parallel striations, but more frequently producing patterns of complicated designs. One of these rocks was described by Dr Williams, who thought there was no question but that it was originally a glass. Perlitic cracks, now filled with calcite and silica, cross many sections, exhibiting beautifully a rudely concentric series of rings. Occasionally the rhyolites contain small porphyritic crystals, but usually they are non-porphyritic.

The tuffs associated with the rhyolites are as characteristic as those associated with the more basic rocks. Their structure, if not their composition, has so frequently been preserved that no one can doubt their true nature. Of course it is impossible to declare positively, without much study, that some of the fragments are glass, but it is the opinion of the speaker that they are.

A few of the rocks which are provisionally classed with the tuffs appear to contain water-worn grains, and some of them seem to be composed mainly of this material. It may be that by further investigation we shall learn whether the old volcano was terrestrial or submarine.

The spherulitic phases of the rhyolites require no detailed mention. The specimens show for themselves. Although there are, of course, very many small secondary spherulites in these old rocks, the larger ones are believed to be unquestionably original, not necessarily with respect to their material, but with respect to their structure, which, by the way, is as beautifully radial as it is in some of the spherulites described by Cross from Colorado. Some of the spherulites in these rocks are hollow and a few possess other lithophysal characters, so that it seems possible to match in these old eastern rocks most of the peculiarities of the modern lavas of the far west.

From this very brief and by no means satisfactory description of the rocks about Vinal Haven and North Haven it would seem that we have in this region nearly every variety of rock characteristic of volcanic regions. Since we know no way by which a bedded series of glassy and crystalline rocks, amygdaloids and tuffs may be laid down except through volcanic agency, we are led perforce to the conclusion that in ancient times a volcano was situated in the neighborhood of Penobscot bay, and that from it as a center lavas and ashes were spread over the surrounding region. It is hoped that a search will reveal the exact location of the vent through which these products were erupted. Mr G. O. Smith will probably make the study of the rocks the subject of his thesis at the Johns Hopkins University, so that we may hope soon to know something more definite about their relations to the Niagara limestone and sandstones with which they are associated than is known at present.

The paper was discussed by A. C. Lane, J. P. Iddings, Whitman Cross, J. E. Wolff, J. F. Kemp, T. G. White (by invitation), W. S. Yeates and C. H. Hitchcock.

The following two papers were by the same author:

## *PERIPHERAL PHASES OF THE GREAT GABBRO MASS OF NORTHEASTERN MINNESOTA*

BY W. S. BAYLEY

Remarks were made by A. C. Lane. The paper is published in the Journal of Geology, volume ii, pages 814–825, and volume iii, pages 1–20.

The following was an exhibition of specimens:

## *CONTACT PHENOMENA AT PIGEON POINT, MINNESOTA*

BY W. S. BAYLEY

This paper is published as Bulletin 109 of the United States Geological Survey.

The last paper of the section was—

## *A NEW INTRUSIVE ROCK NEAR SYRACUSE*

BY N. H. DARTON AND J. F. KEMP

[*Abstract*]

*Contents*



### Geology (by N. H. Darton)

The dike was brought to my attention by Mr P. H. Schneider, of Syracuse, and to him I am also indebted for information regarding some of the relations. The locality is on the top of an isolated hill half a mile south of Dewitt Center (Desono station), about three miles east of Syracuse. The dike was exposed by excavations for the reservoir, and does not appear to have reached the natural surface. It was buried under a mantle of glacial drift, and in part at least covered by shales and limestones of the Salina formation. Unfortunately the reservoir was completed and partially filled with water before Mr Schneider learned of the dike, so that he was unable to observe the relations. According to the statements of the contractor, the rock occurred in masses imbedded in a greenish, yellow earth, which underlaid the entire area of the excavation, about 200 by 250 feet. Some of the masses were 20 by 50 feet.

The greenish yellow earth in which those masses occurred is undoubtedly a decomposition product from the intrusive rock. The original surfaces of the masses themselves are more or less deeply decomposed to a serpentinous matter, and some of the smaller ones are thoroughly altered to secondary products, which are filled with calcite veins. Whether the mass is a dike or an intruded sheet was not determined, but it is probably the former. No traces of the rock have been found in wells or on the surface in the vicinity.

The dike at Dewitt is in the upper portion of the Salina formation, which consists of shales and limestones. A short distance south the slopes of the Helderberg escarpment arise, and to the north are wide plains of the Salina beds. The dip is that of a gentle monocline to the southward. The rocks adjoining the intrusive dike present signs of slight metamorphism, as indicated by increase in hardness and darkening of color. Mr Schneider has called my attention to an exposure 600 yards north of the reservoir in which there is considerable flexing of the shales, but this was the only sign of disturbance noted.

The intrusion contains many inclusions of various rocks, which will be referred to by Professor Kemp. The relations of the Dewitt dike to the similar occurrences at Syracuse are not known, but it is probable that they are connected underground. A search should be made for other dikes in the region.

### Petrography (by J. F. Kemp)

The dike is a peridotite very similar to the one earlier discovered at Syracuse, but it is much fresher than anything collected there. It has large and abundant porphyritic crystals of olivine, which are perfectly unaltered, even the usual change to serpentine failing in many. There are also a few phenocrysts of monoclinic pyroxene, and considerable brown biotite in hexagonal crystals. The original

groundmass was probably a glass, but it is now mostly devitrified by alteration. It contains innumerable minute green augites, shreds of biotite, many magnetite grains to a slight degree chromiferous, not a few very small perofskites, and apatite. It was verbally stated at the Baltimore meeting that no perofskite had been detected, but later, when high powers were used, many grains supposed to be opaque proved to be translucent, isotropic and brown. An analysis by Dr H. Stokes, of the United States Geological Survey, gave the following results:

| | | | |
|---|---|---|---|
| $SiO_2$ | 36.80 | $Na_2O$ | 0.17 |
| $TiO_2$ | 1.26 | $P_2O_5$ | 0.47 |
| $Al_2O_3$ | 4.16 | $CO_2$ | 2.95 |
| $Cr_2O_3$ | 0.20 | $SO_3$ | 0.06 |
| FeO | 8.33 | S | 0.95 |
| MnO | 0.13 | $H_2O$ below 110° | 0.51 |
| NiO | 0.09 | $H_2O$ above 110° | 6.93 |
| CaO | 8.63 | | |
| BaO | 0.12 | Total | 100.22 |
| SrO | tr. | Less O=S | .47 |
| MgO | 25.98 | | |
| $K_2O$ | 2.48 | | 99.75 |

Coarsely crystalline inclusions of a syenitic or dioritic composition were also found, which are probably the "accretions" referred to by Vanuxem in 1835. They appear to be inclusions brought up from the underlying Archean crystallines. In comparative observation on some specimens of the dike described by Dr G. H. Williams from Syracuse, and given to the writer five years ago, undoubted Archean gneiss was detected, corroborating a previous observation of Dr Williams.* The Dewitt dike has many inclusions of shale and of fossiliferous limestone, but in the slides they show no appreciable effects of contact metamorphism. From a number of well records in the neighborhood it was inferred that the dike had come up through about 4,000 feet of Paleozoic strata and an unknown amount of Archean crystalline rocks.

The paper will be published in full in the American Journal of Science.

The petrographic section, at 5.30 o'clock p m, adjourned *sine die.*

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## Session of Friday Evening, December 28

The evening session was held in Levering hall at 7.30 o'clock p m, and was wholly devoted to the Presidential Address, which was illustrated with lantern views, and entitled:

### *RECENT GLACIAL STUDIES IN GREENLAND*

BY THE PRESIDENT, THOMAS C. CHAMBERLIN

The address of the President is printed as pages 199–220 of this volume.

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* Bull Geol. Soc. Am., vol. 1, 1889, p. 533.

Following the adjournment of the evening session the Fellows of the Society assembled for the annual informal dinner, which was served in the geological laboratory. Professor B. K. Emerson acted as master of ceremonies and extemporaneous speeches were made by several Fellows.

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## Session of Saturday, December 29

The Society convened in the geological laboratory at 10 o'clock a m, the President in the chair. Announcement was made concerning railroad tickets, but no business was offered.

The reading of scientific papers was resumed, and the following two papers were read and discussed as a unit:

## *CRETACEOUS DEPOSITS OF THE NORTHERN HALF OF THE ATLANTIC COASTAL PLAIN*

BY WILLIAM B. CLARK

*Contents*



### Historical Review

During the last few years considerable attention has been devoted to the Cretaceous deposits of the area north of the Potomac river, in Maryland, Delaware and New Jersey. The northern and southern portions of this district have been, however, in the main independently investigated, so that the relationships existing between the two areas have not been very clearly indicated. Some recent work by the writer and two of his students * shows that the strata of the entire region can be correlated, the main divisions hitherto established for the New Jersey series continuing to the southward across Delaware and Maryland.

Until comparatively recently no satisfactory differentiation had been made in the Cretaceous strata of the southern portion of the district, although the basal clays and sands or Potomac formation were recognized by the older geologists, and were fully described in 1888 † by McGee.

* Messrs D. E. Roberts and R. M. Bagg, Jr, conducted the investigations upon the "Eastern shore" of Maryland.

† Three formations of the middle Atlantic slope: Am. Jour. Sci., 3d ser., vol. xxxv, pp. 126–143.

Shortly after highly fossiliferous strata were found by the writer * in Anne Arundel and Prince Georges counties, Maryland, and described in 1889 as the equivalent of the lower greensand beds. A further account of the same deposits was published a little later by Uhler.† In 1890 Darton ‡ gave the general name of Severn formation to these strata. It is now known that an extensive series of greensands, also of Cretaceous age, is found above the Severn.

In the state of New Jersey the Cretaceous has long been a subject of investigation, a classification being proposed by the late Professor Cook, which with some important modifications and the substitution of place names, has been adopted by the writer.

## The Formations

### CLASSIFICATION

The classification proposed in an earlier publication for the Cretaceous strata in eastern New Jersey is as follows: §

| Formations. | | Economic equivalents. |
|---|---|---|
| Manasquan | = | Upper marl bed (lower part). |
| Rancocas | = | Middle marl bed. |
| Redbank | = | Red sand. |
| Navesink | = | Lower marl bed. |
| Matawan | = | Clay marls. |
| Raritan | = | Plastic clay. |

### DISTRIBUTION

With the exception of the Rancocas formation, which receives its name from an important creek in Burlington county, New Jersey, all the other divisions of the Cretaceous have been named from typical localities in Monmouth county. Although the terms employed have thus been taken from local areas in the extreme northern portion of the district, the formations have an extremely persistent character and wide range. In the case of the lower divisions, representatives are found extending throughout New Jersey, Delaware and Maryland, reaching from Raritan bay to the Potomac river, while the upper divisions are often buried beneath the later deposits which unconformably overlie them.

### RARITAN FORMATION

The Raritan consists of alternating beds of sand and clay, which change in thickness and texture so rapidly that no section is typical except within narrow limits. The strata extend across central New Jersey and thence, bordering the Delaware river on both its Pennsylvania and New Jersey banks, are continued in the Potomac formation of Maryland and more southern latitudes.

The evidence of paleobotany seems to point to a later phase of deposition in the Raritan than in the Potomac, but it is probable that they are largely of similar age and origin. More extended study of the flora is important for the final determination of this point, and geologists are greatly indebted to Professor Lester F. Ward

* Johns Hopkins University Circular, no. 69, pp. 20, 21.

† Trans. Maryland Acad. Sci., vol. i, pp. 11–32.

‡ Bull. Geol. Soc. Am., vol. 2, pp. 438, 439.

§ Journal of Geology, vol. ii, pp. 161–177.

and his colaborers for the valuable contributions which they are making to our knowledge of the fossil plants of these formations.

###### MATAWAN FORMATION

The Matawan shows remarkable persistence in both its lithological and paleontological characteristics. It consists of dark colored clays with interbedded layers of sand, the former highly micaceous and at times glauconitic, the greensand, however, occurring in relatively thin beds and, for the most part, locally developed. In this respect it differs from the overlying formations, where the greensand is evenly distributed, and from the Raritan, which lacks it altogether. The character of the fossils indicates marine conditions and a profusion of molluscan life. Fossiliferous localities have been found at Keyport, Crosswicks, Pensauken and other points in New Jersey along the line of strike and upon the Chesapeake and Delaware canal, the Magothy river, the Severn river and at Millersville and Fort Washington, in Maryland. Throughout this long distance are found the same characteristic, dark micaceous, sandy clays and similar fauna.

###### NAVESINK FORMATION

The Navesink, characterized by its highly glauconitic strata, extends from the shores of Raritan bay with almost continuous outcrop across New Jersey. It is profusely fossiliferous at numerous points and, with its large and well preserved specimens of *Exogyra costata* and *Gryphæa vesicularis* as well as the common *Belemnitella americana*, is readily recognized.

The Navesink formation outcrops in Delaware along the line of the Chesapeake and Delaware canal, extending thence southeastward to the drainage of Big Bohemia creek, and beyond the Chesapeake appears certainly as far south as Seat Pleasant, in Prince Georges county, where highly fossiliferous beds occur. It probably has a wider distribution to the southward. In general the deposits are less fossiliferous in Maryland than in New Jersey and the lithological distinctions are also less sharply defined.

###### REDBANK FORMATION

The Redbank consists typically of red sands, more or less glauconitic, although the green grains of that mineral have been extensively altered on account of the loose arenaceous character of most of the beds. The Redbank formation is a prominent factor in the New Jersey series, where its bright red color is one of the most striking features throughout the marl district.

On the "Eastern shore" of Maryland, as at Bohemia mills, it retains most of its northern characters, but south of the Chesapeake it becomes more of a grayish green in color, the glauconite being less oxidized and the formation as a whole not easily distinguished, if, indeed, it can be separated from the Navesink formation which underlies it.

###### RANCOCAS FORMATION

The Rancocas consists of thick bedded greensand strata highly glauconitic and weathering to a compact, deep red deposit upon its thinned out and exposed margins. In New Jersey the strata are highly fossiliferous, especially the *Terebratula harlani* zone, which is the most persistent fossiliferous horizon in the state.

The Rancocas formation has been traced to the eastern counties of Maryland, where it occurs well exposed and highly fossiliferous on the upper Sassafras river

and its tributaries. On the western shore of the Chesapeake it is less clearly defined, although evidence of the presence of the *Terebratula harlani* zone * is not wanting.† Its lithological features also are not so sharply marked upon the western as upon the eastern side of Chesapeake bay, the formation as a whole being more arenaceous in Maryland than in New Jersey.

### *MANASQUAN FORMATION*

The Manasquan, so far as known, does not extend beyond the limits of New Jersey, where it occurs as a very fine greensand, the high proportion of soluble phosphates making it the most valuable economically of all of the marl deposits. The fauna shows little in common with the preceding formation.

In southern New Jersey and in the area to the southward, in Delaware and Maryland, the extensive covering of Tertiary and Quaternary strata renders the discovery of the Manasquan formation highly doubtful, if, indeed, it was ever deposited.

### Summary

Summarizing what has been already said, we find that the Raritan and Matawan formations are most widely extended, stretching throughout the entire district, while the Navesink, Redbank and Rancocas formations are well developed in Delaware and the "Eastern shore" of Maryland, and also outcrop in many places to the south of Chesapeake bay. The Manasquan formation, however, has not been found beyond the limits of New Jersey.

## *MARGINAL DEVELOPMENT OF THE MIOCENE IN EASTERN NEW JERSEY*

BY WILLIAM B. CLARK

The two papers by Professor Clark were discussed by N. H. Darton, H. S. Williams, T. W. Stanton and the author.

The following paper was read by title:

## *CRETACEOUS OF WESTERN TEXAS AND COAHUILA, MEXICO*

BY E. T. DUMBLE

This paper is printed as pages 375–388 of this volume.

The next paper was entitled—

## *SEDIMENTARY GEOLOGY OF THE BALTIMORE REGION*

BY N. H. DARTON

Remarks were made by Warren Upham.

* P. R. Uhler: Trans. Maryland Acad. Sci., vol. 1, p. 97–104.

† Since the presentation of this paper several specimens of *Terebratula harlani* from the Severn River region have been secured, while the overlying horizon at the top of the Rancocas formation, and known as the "Yellow limestone" in New Jersey, has been detected. The following characteristic fossils have been obtained from it: *Goniaster mammillata*, *Cidaris splendens*, *Gryphæa bryani* and *Gryphæaostrea vomer*.

The following paper was then read:

## *SURFACE FORMATIONS OF SOUTHERN NEW JERSEY*

BY ROLLIN D. SALISBURY

*Contents*



### Beacon Hill Formation

#### *DISTRIBUTION, ALTITUDE AND DEFORMATION*

The post-Cretaceous surface materials south of the Triassic belt of New Jersey are believed to be divisible into several distinct formations. The oldest of these several formations caps the series of more or less elevated and isolated hills which crosses the state from the northeast to the southwest along the strike of the Cretaceous beds and which includes the Navesink highlands, the Mount Pleasant hills, the hills in the vicinity of Perrineville, Mechanicsville and Ellisdale and the isolated elevations known as Arneys mount, mount Holly, mount Laurel and the ridge near Juliustown. These hills are of very unequal altitude. In the Navesink highlands the base of the oldest member of the "yellow gravel" series has a minimum elevation of less than 200 feet. In the Mount Pleasant hills its elevation is something like 360 feet; in the Perrineville hills (Pine hill) it is about 270 feet; near Ellisdale about 210 feet; in mount Holly about 150 feet. These figures show that the base of the formation rises along the strike of the Cretaceous beds from the Navesink highlands to the Mount Pleasant hills, and that it declines thence to the southwest. On the Delaware, near the mouth of Pensauken creek, its base has less than half the elevation it possesses in mount Holly. In all the hills mentioned the formation under description rests on the Middle marl.

North of this series of isolated remnants of the oldest member of the "yellow gravel" series, the formation is known with certainty in but two places, and these are near each other. Both lie to the north of Monmouth Junction. One is the Sand hills two or three miles north of the station, and the other is a small area four or five miles farther northwest and about two miles northeast of Rocky hill. In the Sand hills the base of the formation has an elevation of about 200 feet and rests on the Raritan clay.

Southeast of the series of hills already mentioned remnants of the formation in question are found at lower altitudes. At the same time the areas where the remnants occur become larger and less isolated. Still farther to the southeast they become continuous.

From the topographic distribution of the formation it is clear that its lack of continuity toward the northwest and its continuity toward the southeast are the result of relative elevation. The formation was lifted higher and therefore eroded more to the northwest. To the southeast it was never sufficiently elevated to allow of great erosion. The southward dip of the formation is nearly but not quite as great as that of the Cretaceous beds. Along the east coast its base reaches the sealevel near the mouth of Shark river, in the vicinity of Asbury Park. Across the state the base of the same formation reaches nearly to sealevel in the vicinity of Philadelphia.

For the present the term Beacon Hill is proposed for this formation because of its characteristic development on the hill of that name near Matawan.

### *COMPOSITION*

The Beacon Hill formation is composed of gravel and sand in varying proportions and relations. On the whole, where existing remnants are thick, there is more sand than gravel. Where they are thin, there is more gravel than sand. This holds true, at least, along the northwestern portions of the area, where the formation occurs in isolated areas. Where the gravel is more conspicuous its abundance is probably the result of the removal of the finer material, the coarser being left behind. Where sand is the more prominent constituent of the formation the original condition of the formation is better represented.

In constitution, the sand and gravel are essentially quartzose. The gravel consists of quartz, chert, flint, silicified fossils, sandstone and, less commonly, of bits of quartzite. Much of the quartz appears to be of vein origin. Some of it may well have come from the abundant vein-fillings in the Hudson River formation in the northern part of the state. In no single instance has this formation been found to contain red shale (Triassic) fragments or pieces of trap, crystalline or gneissic rock of any sort or limestone. Neither does it ever contain, so far as observed, conglomerate or ironstone, both of which are very characteristic constituents of the other members of the "yellow gravel" series. The formation itself is sometimes cemented, so as to constitute a conglomerate, but conglomerate does not enter into its make-up as a constituent. In places the gravel is very uniform and fine, the pebbles being mainly half an inch or so in diameter, but it is sometimes much coarser, and frequently carries large cobbles of quartz or sandstone. Rarely it contains blocks (rather than bowlders) of sandstone a foot or more in diameter. Coarse gravel occurs at various horizons from top to bottom of the formation.

### *THICKNESS AND EXTENSION*

The thickness of the formation or of its existing remnants varies greatly. In the Navesink highlands it has a maximum thickness of about 100 feet. In the Mount Pleasant hills its greatest thickness can hardly be more than 40 feet. In Pine hill near Perrineville its thickness is about 100 feet, while at mount Holly about 30 feet of it remain. In the Sand hills north of Monmouth Junction there is a thickness of about 100 feet. In the Hominy hills near Farmingdale its thickness must approach 200 feet. The highest of these figures must fall short of the original thickness of the formation.

The original northward extension of the formation is unknown, but it would seem that it must have reached at least as far north as the Watchung mountains. There is some reason to believe that it extended even farther in this direction.

###### AGE OF THE FORMATION

It has long been insisted * that this member of the "yellow gravel" series was much older than the Pleistocene. On the basis of certain identifications which have been made by Professor Clark in the vicinity of Freehold, the various isolated remnants of sand and gravel in the positions specified are regarded as Miocene. The argument is simply this: If Professor Clark's identification of Miocene beds near Freehold be correct, all the dissevered remnants here referred to are also Miocene. Professor Clark thinks that these beds are to be connected with formations farther south, which carry fossils by means of which their Miocene age can be fixed.

###### OROGENIC AND EROSIVE CHANGES

The distribution of the formation is such as to show that after it was deposited there was a very considerable uplift, accompanied by a very considerable deformation, both of the Beacon Hill and the Cretaceous beds, and that a long period of erosion followed. This was more effective to the north, where the formation was high, and was less effective to the south, where the formation was low.

During this erosion interval the northern part of the present Cretaceous area of the state was cut down nearly to a plain. High hills remained at a few points only. After the surface was reduced to a peneplain it would appear that valleys were cut in it down nearly to the present level of the sea. This condition of things would seem to suggest a bifold elevation. After the first the peneplain was developed, and after the elevation of the peneplain valleys were cut in the same. Before they became wide, subsidence set in, and the lower part of the peneplained surface was again brought below the level of the sea.

## Pensauken Formation

###### DISTRIBUTION

On this surface was accumulated the second member of the "yellow gravel" series. This is known as the Pensauken formation, from the locality near the mouth of Pensauken creek, just below Palmyra, where the formation is well exposed. It is also well exposed in the high hills in South Amboy, in the lower part of the railway cuts near Jamesburg, and at numerous points in the vicinity of Hightstown and Newtown.

###### COMPOSITION

This formation has among its constituents all sorts of materials which the Miocene beds contain, including Miocene conglomerate. It also contains materials from the Cretaceous beds which underlie the Miocene, and which had been exposed by the erosion which followed deposition of the Miocene and which preceded the deposition of the Pensauken. The Pensauken also contains fragments of shale and sandstone from the Triassic formation, as well as fragments of trap, gabbro, gneiss, granite, chert, Medina and Oneida sandstone and conglomerate, and probably fragments from the Green Pond Mountain conglomerate. This last

*See Annual Reports of the State Geologist of New Jersey for 1891, p. 108; 1892, p. 166; 1893, pp. 39-52.

element is in some doubt, since small fragments of this conglomerate are not always to be distinguished with certainty from bits of Medina and Oneida. Thus it will be seen that the Pensauken formation is lithologically very much more heterogeneous than the preceding Miocene.

The physical condition of the constituents of the Pensauken beds is significant. The granitic and gneissic material is uniformly thoroughly decomposed. Enough of this material was present to render the beds, in their present decomposed condition, distinctly arkose. This is especially true in the northern part of the formation. The trap and gabbro fragments are less completely decomposed, but are always decayed to a considerable distance from the surface. Occasional gabbro bowlders, as well as certain bowlders of gneissic character, are found, sources for which are not known within the state of New Jersey. The bowlders sometimes reach a considerable size, being two, three and even four feet in diameter. In no instance has one of these bowlders been seen to be striated. This evidence is no more than negative, since nothing except the sandstone and quartzite bowlders are sufficiently well preserved to have retained striæ, even if they were once present.

#### *DEVELOPMENT AND THICKNESS*

The Pensauken formation is best developed just south of the Triassic belt which reaches from South Amboy to Trenton, but isolated remnants of it occur much farther north. The most northern well preserved remnants which have been certainly identified occur north and northwest of Somerville and south of the outermost Watchung mountain. There are, very possibly, remnants of the same formation farther north.

The original thickness of the Pensauken formation across the middle portion of the state appears to have been something like 30 feet on the average. In some places its thickness is considerably greater than this, but where this is true the formation appears to fill the narrow valleys which were cut in the peneplain, on which the Pensauken gravel as a whole was deposited.

#### *OROGENIC AND EROSIVE CHANGES*

Elevation and emergence followed the deposition of the Pensauken beds. How far southward the emergence extended is not known, but it certainly affected the central portion of the state, including most if not all the area represented on the geological map of New Jersey as Cretaceous. On this Pensauken surface a drainage system was developed, the valleys being comparable in depth to those which exist today. They were sufficiently wide to indicate that the period necessary for their development was considerable. From the Cretaceous belt of the state something like half the Pensauken formation was removed. The shape and the depth of the valleys cut at this time indicate that the land was not high, and that they developed slowly.

### Jamesburg Formation

#### *ORIGIN AND COMPOSITION*

Then followed a period of subsidence and partial submergence, during which the sea reached an elevation of about 130 feet from Trenton to New Brunswick. During this submergence there was deposited a mantle of gravel and loam, derived principally from the Cretaceous, the Pensauken and the Miocene formations. This constitutes the third of the "yellow gravel" formations, and is for the present known as the Jamesburg formation.

During its deposition the Triassic shale seems to have made no contribution to the gathering formation. The stony material of the Jamesburg is for the most part such as could have been derived from the Pensauken beds. None of the decomposed materials of the Pensauken, however, entered into the composition of the Jamesburg. Such granitic and gneissic materials, as well as such Triassic shale and sandstone of the Pensauken as came within reach of the waters which deposited the Jamesburg, were so thoroughly disrupted that their identity was lost.

#### TOPOGRAPHIC FEATURES AND THEIR HISTORY

The topography which was developed as the result of the submergence which made the Jamesburg formation is peculiar. It is a topography which resulted from the temporary submergence of an erosion surface developed in incoherent materials. In some cases deposits were made by currents running across the shallow pre-Jamesburg valleys in such wise as to divide them into a series of isolated or semi-isolated hollows. In many instances these hollows are now occupied by ponds and marshes. The marshiness which prevails along streams in much of central and southern New Jersey is believed to be due to the deposits which were made during this time. Subsequent erosion has been insufficient to remove the obstructions then developed. The average depth of the Jamesburg formation is perhaps not more than 10 feet, though it sometimes reaches 30 feet.

Elevation followed the submergence and the Jamesburg formation was brought above the water. The emergence was either slight or recent, for drainage has made but little headway in the establishment of new valleys and in the removal of the obstructions deposited in the old ones during the Jamesburg depression.

#### RELATION TO THE TRENTON GRAVEL

Subsequently the Trenton gravels were deposited in the Delaware valley by the glacial waters of the last ice epoch which affected New Jersey. How far the Jamesburg loam and the Trenton gravel are separated in time is undetermined. It is probable that they are sufficiently distinct to be referred to different epochs. In origin they were certainly diverse, even if the interval between them was not long.

### The coastal Terrace

In the eastern part of the state, from Raritan bay eastward and southward, there is a low and rather ill defined coastal terrace, with an average elevation of about 45 feet, which is very much younger than the body of the Jamesburg formation. It is not known, however, to be separated from this formation by any considerable interval of time. It is possible that it represents no more than a halting stage in the emergence of the land after the deposition of the more wide spread Jamesburg. It is possible that it is to be connected in time with the Trenton gravels of the Delaware valley. This is a matter for future determination. Even if it marks no more than a temporary level of the sea during the emergence of the land after the Jamesburg deposition, it nevertheless represents a distinct stage in the history of the land surface, and as such demands recognition.

### Conclusions

Little can now be affirmed concerning the relation of these several subdivisions of the "yellow gravel" to formations which have heretofore been recognized. The

clay-loam in the vicinity of Trenton, extensively used for brick, has been regarded as typical Columbia. This clay-loam belongs to the Jamesburg formation. The Pensauken formation underlies it unconformably. To the north the Pensauken is overlain by the extreme edge of the oldest glacial drift, a little north of Somerville, but there are not sufficient data at hand for determining the length of the interval between them. The relations between the two certainly seem to permit the suggestion that the Pensauken may correspond with the Lafayette formation of the south, though this is confessedly uncertain. On the other hand, the occasional bowlders in the Pensauken seem to suggest that ice may have been concerned in their transportation. The oldest glacial drift which has been recognized overlies the Pensauken near Raritan and Somerville and seems to be older than the Jamesburg, although the striated bowlders in this formation clearly indicate that it was made during or after the beginning of the ice period. If the Jamesburg beds do not represent the extra-glacial equivalent of the first glacial epoch, there would seem to be no such representative unless it be the Pensauken. If the Pensauken beds be Pleistocene, there is no stratigraphic or geographic reason why the Beacon Hill gravel may not be Lafayette. At present, nothing seems certain beyond this: The Jamesburg and all later formations are surely Pleistocene. The Pensauken may be Pleistocene or it may be pre-Pleistocene. If the former, the Beacon Hill gravel may be Lafayette or anything older back to Miocene, so far as stratigraphic and geographic relations are concerned. If the latter, the Beacon Hill gravel might still be either early Pliocene or Miocene.

In the absence of the author, the following paper, which was presented to the Society through Professor W. H. Hobbs, was read in abstract by J. P. Iddings:

### *ON THE QUARTZ-KERATOPHYRE AND ITS ASSOCIATED ROCKS OF THE BARABOO BLUFFS, WISCONSIN*

BY SAMUEL WEIDMAN

This paper is published in the science series of the Bulletin of the University of Wisconsin, volume i, number 2, pages 35–56, plates 1–3.

The author of the next paper was absent, and it was read by E. O. Hovey:

### *ON NEW FORMS OF MARINE ALGÆ FROM THE TRENTON LIMESTONE, WITH OBSERVATIONS ON BUTHOGRAPTUS LAXUS, HALL*

BY R. P. WHITFIELD

Remarks were made upon the matter of the paper by H. M. Ami. The paper is published in the Bulletin of the American Museum of Natural History.

The following paper was read, in the absence of the author, by H. M. Ami:

*HONEYCOMBED LIMESTONES IN LAKE HURON*

BY ROBERT BELL

The paper is printed as pages 297–304 of this volume.

The following paper was then read:

*CHARACTERISTIC FEATURES OF CALIFORNIA GOLD-QUARTZ VEINS*

BY WALDEMAR LINDGREN

The paper is printed as pages 221–240 of this volume.

The next paper was entitled:

*DISINTEGRATION OF THE GRANITIC ROCKS OF THE DISTRICT OF COLUMBIA*

BY GEORGE P. MERRILL

The paper is printed as pages 321–332 of this volume.

The last paper of the meeting was then read:

*ANCIENT PHYSIOGRAPHY AS REPRESENTED IN SEDIMENTS*

BY BAILEY WILLIS

The following resolution of thanks was offered by Bailey Willis and was adopted unanimously:

The successful issue of this meeting and the pleasure of the members are in large measure due to the excellent opportunities afforded us at our place of discussion and to the efforts made for our entertainment.

The thanks of the Society are due to the trustees of Johns Hopkins University and its president, Dr Gilman. It is appropriate also that we should recall the strong interest felt by Dr Williams in the prospect of this meeting, and remember that this center of geological instruction and research has been built chiefly through his enthusiastic and faithful work.

To Dr William B. Clark, Dr E. B. Mathews, Mr H. F. Reid, and their fellow-workers of the local societies we are indebted for the perfection of the arrangements which we have enjoyed.

It is therefore moved that the hearty thanks of the Society are extended to the Johns Hopkins University and to all who have so successfully contributed to our entertainment.

The President then declared the seventh annual meeting of the Society adjourned.

## Register of the Baltimore Meeting, 1894

The following Fellows were in attendance upon the meeting:

F. D. Adams.
H. M. Ami.
W. S. Bayley.
G. F. Becker.
H. D. Campbell.
M. R. Campbell.
T. C. Chamberlin.
W. B. Clark.
E. D. Cope.
Whitman Cross.
H. P. Cushing.
N. H. Darton.
D. T. Day.
J. S. Diller.
E. V. d'Invilliers.
B. K. Emerson.
S. F. Emmons.
H. L. Fairchild.
G. K. Gilbert.
A. C. Gill.
L. S. Griswold.
C. W. Hayes.
C. H. Hitchcock.
Jed Hotchkiss.
E. O. Hovey.
E. E. Howell.
J. P. Iddings.
Arthur Keith.
J. F. Kemp.
F. H. Knowlton.
A. C. Lane.
D. F. Lincoln.
Waldemar Lindgren.
W J McGee.
O. C. Marsh.
F. J. H. Merrill.
G. P. Merrill.
H. B. Nason.
W. H. Niles.
L. V. Pirsson.
H. F. Reid.
W. N. Rice.
Heinrich Ries.
I. C. Russell.
R. D. Salisbury.
W. B. Scott.
N. S. Shaler.
J. C. Smock.
C. H. Smyth, Jr.
J. W. Spencer.
J. Stanley-Brown.
T. W. Stanton.
J. J. Stevenson.
H. W. Turner.
Warren Upham.
C. D. Walcott.
David White.
I. C. White.
H. S. Williams.
Bailey Willis.
J. E. Wolff.
G. F. Wright.
W. S. Yeates.

*Fellows-elect.*

Collier Cobb.

Total attendance, 64.

# OFFICERS AND FELLOWS OF THE GEOLOGICAL SOCIETY OF AMERICA

## *OFFICERS FOR 1895*

*President*

N. S. Shaler, Cambridge, Mass.

*Vice-Presidents*

Joseph Le Conte, Berkeley, Cal.
C. H. Hitchcock, Hanover, N. H.

*Secretary*

H. L. Fairchild, Rochester, N. Y.

*Treasurer*

I. C. White, Morgantown, W. Va.

*Editor*

J. Stanley-Brown, Washington, D. C.

*Councillors*

(Term expires 1895)

E. A. Smith, University, Ala.
C. D. Walcott, Washington, D. C.

(Term expires 1896)

F. D. Adams, Montreal, Canada.
I. C. Russell, Ann Arbor, Mich.

(Term expires 1897)

R. W. Ells, Ottawa, Canada.
C. R. Van Hise, Madison, Wis.

## *FELLOWS, APRIL, 1895*

* Indicates Original Fellow (see article III of Constitution)

Frank Dawson Adams, Ph. D., Montreal, Canada; Professor of Geology in McGill University. December, 1889.

Truman H. Aldrich, M. E., 92 Southern Ave., Cincinnati, Ohio. May, 1889.

Henry M. Ami, A. M., Geological Survey Office, Ottawa, Canada; Assistant Paleontologist on Geological and Natural History Survey of Canada. December, 1889.

Alfred E. Barlow, B. A., M. A., Geological Survey Office, Ottawa, Canada; Assistant Geologist on Canadian Geological Survey. August, 1892.

George H. Barton, B. S., Boston, Mass.; Instructor in Geology in Massachusetts Institute of Technology. August, 1890.

Florence Bascom, A. M., B. S., Ph. D., Columbus, Ohio; Instructor in Geology, Petrography and Mineralogy in the Ohio State University. August, 1894.

William S. Bayley, Ph. D., Waterville, Maine; Professor of Geology in Colby University. December, 1888.

*George F. Becker, Ph. D., Washington, D. C.; U. S. Geological Survey.

Charles E. Beecher, Ph. D., Yale University, New Haven, Conn. May, 1889.

Robert Bell, C. E., M. D., LL. D., Ottawa, Canada; Assistant Director of the Geological and Natural History Survey of Canada. May, 1889.

Albert S. Bickmore, Ph. D., American Museum of Natural History, 77th St. and Eighth Ave., N. Y. city; Curator of Anthropology in the American Museum of Natural History. December, 1889.

William P. Blake, New Haven, Conn.; Mining Engineer. August, 1891.

Ezra Brainerd, LL. D., Middlebury, Vt.; President of Middlebury College. December, 1889.

*John C. Branner, Ph. D., Menlo Park, Cal.; Professor of Geology in Leland Stanford Jr. University; State Geologist of Arkansas.

Albert Perry Brigham, A. B., A. M., Hamilton, N. Y.; Professor of Geology and Natural History, Colgate University. December, 1893.

*Garland C. Broadhead, Columbia, Mo.; Professor of Geology in the University of Missouri.

*Walter A. Brownell, Ph. D., 905 University Ave., Syracuse, N. Y.

Henry P. H. Brumell, Geölogical Survey Office, Ottawa, Canada; Assistant Geologist on Canadian Geological Survey. August, 1892.

*Samuel Calvin, Iowa City, Iowa; Professor of Geology and Zoölogy in the State University of Iowa. State Geologist.

Henry Donald Campbell, Ph. D., Lexington, Va.; Professor of Geology and Biology in Washington and Lee University. May, 1889.

Marius R. Campbell, U. S. Geological Survey, Washington, D. C. August, 1892.

Franklin R. Carpenter, Ph. D., Rapid City, South Dakota; Professor of Geology in Dakota School of Mines. May, 1889.

Robert Chalmers, Geological Survey Office, Ottawa, Canada; Field Geologist on Geological and Natural History Survey of Canada. May, 1889.

* T. C. Chamberlin, LL. D., Chicago, Ill.; Head Professor of Geology, University of Chicago.

Clarence Raymond Claghorn, B. S., M. E., Vintondale, Pa. August, 1891.

* William B. Clark, Ph. D., Baltimore, Md.; Professor of Geology in Johns Hopkins University.

* Edward W. Claypole, D. Sc., Akron, O.; Professor of Natural Science in Buchtel College.

Julius M. Clements, B. A., Ph. D., Madison, Wis.; Assistant Professor of Geology in University of Wisconsin. December, 1894.

Collier Cobb, A. B., A. M., Chapel Hill, N. C.; Professor of Geology in University of North Carolina. December, 1894.

* Theodore B. Comstock, Tucson, Ariz.; President of the University of Arizona.

* Edward D. Cope, Ph. D., 2102 Pine St., Philadelphia, Pa.; Professor of Geology in the University of Pennsylvania.

* Francis W. Cragin, B. S., Colorado Springs, Col.; Professor of Geology and Natural History in Colorado College.

*Albert R. Crandall, A. M., Milton, Wis.

* William O. Crosby, B. S., Boston Society of Natural History, Boston, Mass.; Assistant Professor of Mineralogy and Lithology in Massachusetts Institute of Technology.

Whitman Cross, Ph. D., U. S. Geological Survey, Washington, D. C. May, 1889.

Garry E. Culver, A. M., 1104 Wisconsin St., Stevens Point, Wis. December, 1891.

* Henry P. Cushing, M. S., Cleveland, Ohio; Associate Professor of Geology, Adelbert College.

T. Nelson Dale, Williamstown, Mass.; Geologist, U. S. Geological Survey, Instructor in Geology, Williams College. December, 1890.

* Nelson H. Darton, United States Geological Survey, Washington, D. C.

* William M. Davis, Cambridge, Mass.; Professor of Physical Geography in Harvard University.

George M. Dawson, D. Sc., A. R. S. M., Geological Survey Office, Ottawa, Canada; Assistant Director of Geological and Natural History Survey of Canada. May, 1889.

Sir J. William Dawson, LL. D., McGill College, Montreal, Canada; Principal of McGill University. May, 1889.

David T. Day, A. B., Ph. D., U. S. Geological Survey, Washington, D. C. August, 1891.

Antonio del Castillo, School of Engineers, City of Mexico, Director of National School of Engineers; Director Geological Commission, Republic of Mexico. August, 1892.

Frederick P. Dewey, Ph. B., 621 F St. N.W., Washington, D. C. May, 1889.

Orville A. Derby, M. S., Sao Paulo, Brazil; Director of the Geographical and Geological Survey of the Province of Sao Paulo, Brazil. December, 1890.

* Joseph S. Diller, B. S., United States Geological Survey, Washington, D. C.

Edward V. d'Invilliers, E. M., 711 Walnut St., Philadelphia, Pa. December, 1888.

* Edwin T. Dumble, Austin, Texas; State Geologist.

Clarence E. Dutton, Major, U. S. A., Ordnance Department, San Antonio, Texas. August, 1891.

* WILLIAM B. DWIGHT, M. A., Ph. B., Poughkeepsie, N. Y.; Professor of Natural History in Vassar College.

* GEORGE H. ELDRIDGE, A. B., United States Geological Survey, Washington, D. C.

ROBERT W. ELLS, LL. D., Geological Survey Office, Ottawa, Canada; Field Geologist on Geological and Natural History Survey of Canada. December, 1888.

* BENJAMIN K. EMERSON, Ph. D., Amherst, Mass.; Professor in Amherst College.

* SAMUEL F. EMMONS, A. M., E. M., U. S. Geological Survey, Washington, D. C.

JOHN EYERMAN, F. Z. S., Oakhurst, Easton, Pa. August, 1891.

HAROLD W. FAIRBANKS, B. S., Berkeley, Cal.; Geologist State Mining Bureau. August, 1892.

* HERMAN L. FAIRCHILD, B. S., Rochester, N. Y.; Professor of Geology and Natural History in University of Rochester.

J. C. FALES, Danville, Kentucky; Professor in Centre College. December, 1888.

EUGENE RUDOLPH FARIBAULT, C. E., Geological Survey Office, Ottawa, Canada. August, 1891.

P. J. FARNSWORTH, M. D., Clinton, Iowa; Professor in the State University of Iowa. May, 1889.

MORITZ FISCHER, Curator, E. M. Museum, Princeton, N. J. May, 1889.

SANDFORD FLEMING, LL. D., Ottawa, Canada; Civil Engineer. August, 1893.

* ALBERT E. FOOTE, M. D., 1224 N. 41st St., Philadelphia, Pa.

WILLIAM M. FONTAINE, A. M., University of Virginia, Va.; Professor of Natural History and Geology in University of Virginia. December, 1888.

* PERSIFOR FRAZER, D. Sc., 1042 Drexel Building, Philadelphia, Pa; Professor of Chemistry in Franklin Institute.

* HOMER T. FULLER, Ph. D., Springfield, Mo.; President of Drury College.

HENRY GANNETT, S. B., A. Met. B., U. S. Geological Survey, Washington, D. C. December, 1891.

* GROVE K. GILBERT, A. M., United States Geological Survey, Washington, D. C.

ADAM CAPEN GILL, A. B., Ph. D., Ithaca, N. Y.; Assistant Professor of Mineralogy and Petrography in Cornell University. December, 1888.

N. J. GIROUX, C. E., Geological Survey Office, Ottawa, Canada; Assistant Field Geologist, Geological and Natural History Survey of Canada. May, 1889.

CHARLES H. GORDON, M. S., 6046 Washington Ave., Chicago, Ill. August, 1893.

ULYSSES SHERMAN GRANT, Ph. D., Minneapolis, Minn.; Assistant on Geological Survey of Minnesota. December, 1890.

WILLIAM STUKELEY GRESLEY, Erie, Pa.; Mining Engineer. December, 1893.

LEON S. GRISWOLD, A. B., 238 Boston St., Dorchester, Mass. August, 1892.

* WILLIAM F. E. GURLEY, Springfield, Ill.; State Geologist.

ARNOLD HAGUE, Ph. B., U. S. Geological Survey, Washington, D. C. May, 1889.

* CHRISTOPHER W. HALL, A. M., 803 University Ave., Minneapolis, Minn.; Professor of Geology and Mineralogy in University of Minnesota.

* JAMES HALL, LL. D., State Hall, Albany, N. Y.; State Geologist and Director of the State Museum.

HENRY G. HANKS, 1124 Greenwich St., San Francisco, Cal.; lately State Mineralogist. December, 1888.

JOHN B. HASTINGS, M. E., Boisé City, Idaho. May, 1889.

* ERASMUS HAWORTH, Ph. D., Lawrence, Kansas.

* ROBERT HAY, Box 562, Junction City, Kansas; Geologist, U. S. Department of Agriculture.

C. Willard Hayes, Ph. D., U. S. Geological Survey, Washington, D. C. May, 1889.

*Angelo Heilprin, Academy of Natural Sciences, Philadelphia, Pa.; Professor of Paleontology in the Academy of Natural Sciences.

* Eugene W. Hilgard, Ph. D., LL. D., Berkeley, Cal.; Professor of Agriculture in University of California.

Frank A. Hill, 1011 South 48th St., Philadelphia, Pa.; Geologist in Charge of Anthracite District, Second Geological Survey of Pennsylvania. May, 1889.

* Robert T. Hill, B. S., U. S. Geological Survey, Washington, D. C.

Richard C. Hills, Mining Engineer, Denver, Colo. August, 1894.

* Charles H. Hitchcock, Ph. D., Hanover, N. H.; Professor of Geology in Dartmouth College.

William Herbert Hobbs, B. Sc., Ph. D., Madison, Wis.; Assistant Professor of Mineralogy in the University of Wisconsin. August, 1891.

* Levi Holbrook, A. M., P. O. Box 536, New York city.

Arthur Hollick, Ph. B., Columbia College, New York; Instructor in Paleontology. August, 1893.

* Joseph A. Holmes, Chapel Hill, North Carolina; State Geologist and Professor of Geology in University of North Carolina.

Mary E. Holmes, Ph. D., 201 S. First St., Rockford, Illinois. May, 1889.

Thomas C. Hopkins, A. M., University of Chicago, Chicago, Ill. December, 1894.

* Jedediah Hotchkiss, 346 E. Beverly St., Staunton, Virginia.

* Edmund O. Hovey, Ph. D., American Museum of Natural History, New York city.

* Horace C. Hovey, D. D., Newburyport, Mass.

* Edwin E. Howell, A. M., 612 17th St. N. W., Washington, D. C.

Lucius L. Hubbard, A. B., LL. B., Ph. D., Houghton, Mich.; State Geologist of Michigan. December, 1894.

*Alpheus Hyatt, B. S., Bost. Soc. of Nat. Hist., Boston, Mass.; Curator of Boston Society of Natural History.

Joseph P. Iddings, Ph. B., Professor of Petrographic Geology, University of Chicago, Chicago, Ill. May, 1889.

Elfric D. Ingall, Geological Survey Office, Ottawa, Canada; in charge of Mineral Statistics and Mines. August, 1894.

A. Wendell Jackson, Ph. B., 407 St. Nicholas Ave., New York city. December, 1888.

Robert T. Jackson, S. B. S. D., 33 Gloucester St., Boston, Mass.; Instructor of Paleontology in Harvard University. August, 1894.

Thomas M. Jackson, C. E., S. D., Clarksburg, W. Va. May, 1889.

* Joseph F. James, M. S., Department of Agriculture, Washington, D. C.

* Willard D. Johnson, United States Geological Survey, Washington, D. C.

Alexis A. Julien, Ph. D., Columbia College, New York city; Instructor in Columbia College. May, 1889.

Arthur Keith, A. M., U. S. Geological Survey, Washington, D. C. May, 1889.

* James F. Kemp, A. B., E. M., Columbia College, New York city; Professor of Geology.

Charles Rollin Keyes, A. M., Ph. D., Assistant State Geologist, Des Moines, Iowa. August, 1890.

Clarence King, 18 Wall St., New York city. May, 1889.

Frank H. Knowlton, M. S., Washington, D. C.; Assistant Paleontologist U. S. Geological Survey. May, 1889.

* George F. Kunz, care of Tiffany & Co., 15 Union Square, New York.

Ralph D. Lacoe, Pittston, Pa. December, 1889.

George Edgar Ladd, A. B., A. M., 81 Oxford St., Cambridge, Mass. August, 1891.

J. C. K. Laflamme, M. A., D. D., Quebec, Canada; Professor of Mineralogy and Geology in University Laval, Quebec. August, 1890.

Lawrence M. Lambe, Ottawa, Canada; Artist and Assistant in Paleontology and Geological Survey of Canada. August, 1890.

Alfred C. Lane, Ph. D., Houghton, Mich.; Assistant on Geological Survey of Michigan. December, 1889.

Daniel W. Langdon, Jr., A. B., University Club, Cincinnati, Ohio; Geologist of Chesapeake and Ohio Railroad Company. December, 1889.

Andrew C. Lawson, Ph. D., Berkeley, Cal.; Assistant Professor of Geology in the University of California. May, 1889.

* Joseph Le Conte, M. D., LL. D., Berkeley, Cal.; Professor of Geology in the University of California.

* J. Peter Lesley, LL. D., 1008 Clinton St., Philadelphia, Pa.; State Geologist.

Frank Leverett, B. S., Denmark, Iowa; Assistant U. S. Geological Survey. August, 1890.

David F. Lincoln, M. D. August, 1894.

Waldemar Lindgren, U. S. Geological Survey, Washington, D. C. August, 1890.

Robert H. Loughridge, Ph. D., Berkeley, Cal.; Assistant Professor of Agricultural Chemistry in University of California. May, 1889.

Albert P. Low, B. S., Geological Survey Office, Ottawa, Canada; Assistant Geologist on Canadian Geological Survey. August, 1892.

Thomas H. McBride, Iowa City, Iowa; Professor of Botany in the State University of Iowa. May, 1889.

Henry McCalley, A. M., C. E., University, Tuscaloosa county, Ala.; Assistant on Geological Survey of Alabama. May, 1889.

Richard G. McConnell, A. B., Geological Survey Office, Ottawa, Canada; Field Geologist on Geological and Natural History Survey of Canada. May, 1889.

James Rieman Macfarlane, A. B., Pittsburg, Pa. August, 1891.

* W J McGee, Washington, D. C.; Bureau of North American Ethnology.

William McInnes, A. B., Geological Survey Office, Ottawa, Canada; Assistant Field Geologist, Geological and Natural History Survey of Canada. May, 1889.

Peter McKellar, Fort William, Ontario, Canada. August, 1890.

Oliver Marcy, LL. D., Evanston, Cook Co., Ill.; Professor of Natural History in Northwestern University. May, 1889.

Othniel C. Marsh, Ph. D., LL. D., New Haven, Conn.; Professor of Paleontology in Yale University. May, 1889.

Vernon F. Marsters, A. B., Bloomington, Ind.; Associate Professor of Geology in Indiana State University. August, 1892.

P. H. Mell, M. E., Ph. D., Auburn, Ala.; Professor of Geology and Natural History in the State Polytechnic Institute. December, 1888.

* Frederick J. H. Merrill, Ph. D., State Museum, Albany, N. Y.: Assistant State Geologist and Assistant Director of State Museum.

George P. Merrill, M. S., U. S. National Museum, Washington, D. C.; Curator of Department of Lithology and Physical Geology. December, 1888.

James E. Mills, B. S., Quincy, Plumas Co., Cal. December, 1888.

THOMAS F. MOSES, M. D., Urbana, Ohio; President of Urbana University. May, 1889.

*FRANK L. NASON, A. B., 5 Union St., New Brunswick, N. J.; Assistant on Geological Survey of New Jersey.

*PETER NEFF, A. M., 361 Russell Ave., Cleveland, Ohio; Librarian, Western Reserve Historical Society.

FREDERICK H. NEWELL, B. S., U. S. Geological Survey, Washington, D. C. May, 1889.

WILLIAM H. NILES, Ph. B., M. A., Cambridge, Mass. August, 1891.

CHARLES J. NORWOOD, Frankfort, Ky.; State Mine Inspector of Kentucky. August, 1894.

*EDWARD ORTON, Ph. D., LL. D., Columbus, Ohio; State Geologist and Professor of Geology in the State University.

*AMOS O. OSBORN, Waterville, Oneida Co., N. Y.

CHARLES PALACHE, B. S., University of California, Berkeley, Cal. August, 1894.

*HORACE B. PATTON, Ph. D., Golden, Col.; Professor of Geology and Mineralogy in Colorado School of Mines.

RICHARD A. F. PENROSE, Jr., Ph. D., 1331 Spruce St., Philadelphia, Pa. May, 1889.

JOSEPH H. PERRY, 176 Highland St., Worcester, Mass. December, 1888.

*WILLIAM H. PETTEE, A. M., Ann Arbor, Mich.; Professor of Mineralogy, Economical Geology and Mining Engineering in Michigan University.

LOUIS V. PIRSSON, Ph. B., New Haven, Conn.; Assistant Professor of Inorganic Geology, Sheffield Scientific School. August, 1894.

*FRANKLIN PLATT, 1319 Walnut St., Philadelphia, Pa.

*JULIUS POHLMAN, M. D., University of Buffalo, Buffalo, N. Y.

WILLIAM B. POTTER, A. M., E. M., St. Louis, Mo.; Professor of Mining and Metallurgy in Washington University. August, 1890.

*JOHN W. POWELL, Director of U. S. Geological Survey, Washington, D. C.

*CHARLES S. PROSSER, M. S., Schenectady, N. Y.; Professor of Geology in Union College.

*RAPHAEL PUMPELLY, U. S. Geological Survey, Newport, R. I.

HARRY FIELDING REID, Ph. D., Johns Hopkins University, Baltimore, Md. December, 1892.

WILLIAM NORTH RICE, A. M., Ph. D., LL. D., Middletown, Conn.; Professor of Geology in Wesleyan University. August, 1890.

HEINRICH RIES, Ph. B., Fellow in Mineralogy, Columbia College, New York city. December, 1893.

CHARLES W. ROLFE, M. S., Urbana, Champaign Co., Ill.; Professor of Geology in University of Illinois. May, 1889.

*ISRAEL C. RUSSELL, M. S., Ann Arbor, Mich.; Professor of Geology in University of Michigan.

*JAMES M. SAFFORD, M. D., LL. D., Nashville, Tenn.; State Geologist; Professor in Vanderbilt University.

ORESTES H. ST. JOHN, Topeka, Kan. May, 1889.

*ROLLIN D. SALISBURY, A. M., Chicago, Ill.; Professor of General and Geographic Geology in University of Chicago.

FREDERICK W. SARDESON, University of Minnesota, Minneapolis, Minn. December, 1892.

*CHARLES SCHAEFFER, M. D., 1309 Arch St., Philadelphia, Pa.

William B. Scott, M. A., Ph. D., 56 Bayard Ave., Princeton, N. J.; Blair Professor of Geology in College of New Jersey. August, 1892.

Henry M. Seely, M. D., Middlebury, Vt.; Professor of Geology in Middlebury College. May, 1889.

Alfred R. C. Selwyn, C. M. G., LL. D., Ottawa, Canada; Director of Geological and Natural History Survey of Canada. December, 1889.

* Nathaniel S. Shaler, LL. D., Cambridge, Mass.; Professor of Geology in Harvard University.

Will H. Sherzer, M. S., Ypsilanti, Mich.; Professor in State Normal School. December, 1890.

* Frederick W. Simonds, Ph. D., Austin, Texas; Professor of Geology in University of Texas.

* Eugene A. Smith, Ph. D., University, Tuscaloosa Co., Ala.; State Geologist and Professor of Chemistry and Geology in University of Alabama.

James Perrin Smith, M. S., Ph. D., Palo Alto, California; Assistant Professor of Paleontology, Leland Stanford Jr. University. December, 1893.

* John C. Smock, Ph. D., Trenton, N. J.; State Geologist.

Charles H. Smyth, Jr., Ph. D., Clinton, N. Y.; Professor of Geology in Hamilton College. August, 1892.

Henry L. Smyth, A. B., Cambridge, Mass.; Instructor in Mining Geology in Harvard University. August, 1894.

* J. W. Spencer, A. M., Ph. D., 1751 18th St., Washington, D. C.

Josiah E. Spurr, A. B., A. M., Gloucester, Mass. December, 1894.

Joseph Stanley-Brown, Assistant Geologist U. S. Geological Survey, Washington, D. C. August, 1892.

Timothy William Stanton, B. S., U. S. Geological Survey, Washington, D. C.; Assistant Paleontologist U. S. Geological Survey. August, 1891.

* John J. Stevenson, Ph. D., LL. D., University of the City of New York; Professor of Geology in the University of the City of New York.

Ralph S. Tarr, Cornell University, Ithaca, N. Y. August, 1890.

*Asa Scott Tiffany, 901 West Fifth St., Davenport, Iowa.

* James E. Todd, A. M., Vermillion, S. Dak.; Professor of Geology and Mineralogy in University of South Dakota.

* Henry W. Turner, U. S. Geological Survey, Washington, D. C.

Joseph B. Tyrrell, M. A., B. Sc., Geological Survey Office, Ottawa, Canada; Geologist on the Canadian Geological Survey. May, 1889.

* Edward O. Ulrich, A. M., Newport, Ky.; Paleontologist of the Geological Survey of Minnesota.

* Warren Upham, A. M., Librarian Western Reserve Historical Society, Cleveland, Ohio.

* Charles R. Van Hise, M. S., Madison, Wis.; Professor of Mineralogy and Petrography in Wisconsin University; Geologist U. S. Geological Survey.

* Anthony W. Vogdes, Alcatraz Island, San Francisco, Cal.; Captain Fifth Artillery, U. S. Army.

Charles Wachsmuch, M. D., Burlington, Iowa. May, 1889.

* Marshman E. Wadsworth, Ph. D., Houghton, Mich.; State Geologist; Director of Michigan Mining School.

* Charles D. Walcott, U. S. National Museum, Washington, D. C.; Paleontologist U. S. Geological Survey.

Walter H. Weed, M. E., U. S. Geological Survey, Washington, D. C. May, 1889.

Lewis G. Westgate, 1303 Chicago Ave., Evanston, Ill. August, 1894.

Thomas C. Weston, Ottawa, Canada, Assistant Curator Geological Survey Department Museum. August, 1893.

David White, U. S. National Museum, Washington, D. C.; Assistant Paleontologist, U. S. Geological Survey, Washington, D. C. May, 1889.

* Israel C. White, Ph. D., Morgantown, W. Va.

* Charles A. White, M. D., U. S. National Museum, Washington, D. C.; Paleontologist U. S. Geological Survey.

Joseph Frederick Whiteaves, Ottawa, Canada; Paleontologist and Assistant Director Geological Survey of Canada. December, 1892.

* Robert P. Whitfield, Ph. D., American Museum of Natural History, 77th St. and Eighth Ave., New York city; Curator of Geology and Paleontology.

Charles L. Whittle, West Medford, Mass.; Assistant Geologist U. S. Geological Survey. August, 1892.

* Edward H. Williams, Jr., A. C., E. M., 117 Church St., Bethlehem, Pa.; Professor of Mining Engineering and Geology in Lehigh University.

* Henry S. Williams, Ph. D., New Haven, Conn.; Professor of Geology and Paleontology in Yale University.

Bailey Willis, U. S. Geological Survey, Washington, D. C. December, 1889.

* Horace Vaughn Winchell, 1306 S. E. 7th St., Minneapolis, Minn.; Assistant on Geological Survey of Minnesota.

* Newton H. Winchell, A. M., Minneapolis, Minn.; State Geologist; Professor in University of Minnesota.

* Arthur Winslow, B. S., Roe Building, 5th and Pine streets, St. Louis, Mo.

John E. Wolff, Ph. D., Harvard University, Cambridge, Mass.; Assistant Professor in Petrography, Harvard University. December, 1889.

Robert Simpson Woodward, C. E., Columbia College, New York city; Professor of Mechanics in Columbia College. May, 1889.

Albert A. Wright, A. B., Ph. B., Oberlin, Ohio; Professor of Geology in Oberlin College. August, 1893.

* G. Frederick Wright, D. D., Oberlin, Ohio; Professor in Oberlin Theological Seminary.

Lorenzo G. Yates, M. D., Los Angeles, Cal. December, 1889.

William S. Yeates, A. B., A. M., Atlanta, Ga.; State Geologist of Georgia. August, 1894.

## *FELLOWS DECEASED*

* Indicates Original Fellow (see article III of Constitution)

* Charles A. Ashburner, M. S., C. E. Died December 24, 1889.

Amos Bowman, Anacortes, Wash. Died June 18, 1894.

* J. H. Chapin, Ph. D., Meriden, Conn. Died March 14, 1892.

George H. Cook, Ph. D., LL. D. Died September 22, 1889.

* James D. Dana, LL. D. Died April 14, 1895.

David Honeyman, D. C. L. Died October 17, 1889.

Thomas Sterry Hunt, D. Sc., LL. D. Died February, 1892.

* Henry R. Nason, M. D., Ph. D., LL. D., Troy, N. Y. Died January 17, 1895.

* John S. Newberry, M. D., LL. D. Died December 7, 1892.

* Richard Owen, LL. D. Died March 24, 1890.
* George H. Williams, Ph. D., Baltimore, Md. Died July 12, 1894.
* J. Francis Williams, Ph. D. Died November 9, 1891.
* Alexander Winchell, LL. D. Died February 19, 1891.

*Summary*

| | |
|---|---|
| Original Fellows | 90 |
| Elected Fellows. | 133 |
| Membership | 223 |
| Deceased Fellows | 13 |

# ACCESSIONS TO LIBRARY TO JANUARY, 1895

By H. L. Fairchild, *Secretary and Acting Librarian*

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### (*a*) *AMERICA*

NEW YORK STATE MUSEUM, ALBANY

1. Twenty-fourth Annual Report, 1870, pp. 1–232.
2. Thirty-ninth " " 1885, pp. 1-229.

BOSTON SOCIETY OF NATURAL HISTORY, BOSTON

3. Proceedings, vol. xxiv, May, 1888–April, 1890, 3 parts, pp. 1–597.
4. " " xxv, May, 1890–Nov., 1891, 3 parts, pp. 1–523.
5. " " xxvi, Nov., 1891–May, 1894, 2 parts, pp. 1–393.

MUSEO NACIONAL DE BUENOS AIRES, BUENOS AIRES

273. Anales, Tomo iii, pt. ix, 1891, pp. 401–488.

CHICAGO ACADEMY OF SCIENCES, CHICAGO

COLORADO SCIENTIFIC SOCIETY, DENVER

6–8. Proceedings, 1892–1894 (21 separate papers).

NOVA SCOTIAN INSTITUTE OF SCIENCE, HALIFAX

253. Proceedings and Transactions, vol. 7, pt. 4, 1889–'90, pp. 313–523.
254. " " " 2d ser., vol. 1, 3 parts, 1891–'93, pp. 1–379.

NATURAL HISTORY SOCIETY, MONTREAL

255. Canadian Record of Science, vol. v, Nos. 1–4, 8.

NEW YORK ACADEMY OF SCIENCES, NEW YORK

17. Transactions, vol. xi, 1891–'92, Nos. 3–5, pp. 41–104.
18–19. " vols. xii, 1892–'93; xiii, 1893–'94.
20–22. Annals, vols. vi–viii.

AMERICAN MUSEUM OF NATURAL HISTORY, NEW YORK

9–13. Bulletin, vols. i–v, 1881–1893.
14–16. Annual Reports of the President, etc., 1891–93.

ENGINEERING AND MINING JOURNAL, NEW YORK

23. Vol. lii, Nos. 15 (Oct. 10, 1891)–26 (Dec. 26, 1891).
24–29. Vols. lii, 1892–lviii, 1894 (except No. 12 of vol. liii, and No. 10 of vol. lv).

GEOLOGICAL SURVEY OF CANADA, OTTAWA

258–265. Reports of Progress, from 1874 to 1884.
266–272. Annual Reports (new series), vol. i, 1885—vol. v, 1891, with maps. (Vols. iii and v in two parts.)
256. Contribution to Canadian Paleontology, vol. 1, pts. iii and iv; pp. 253–359.
257. Contributions to Canadian Micro-paleontology, pts. iii and iv, 1891–'92, pp. 59–110.

ROYAL SOCIETY OF CANADA, OTTAWA

ACADEMY OF NATURAL SCIENCES, PHILADELPHIA

30–34. Proceedings, vols. 1889–'93.
35. " vol. 1894, 2 parts, pp. 1–288.

AMERICAN PHILOSOPHICAL SOCIETY, PHILADELPHIA

36. Proceedings, vol. xxix, 1891, 2 parts, pp. 1–226.
37. " " xxx, 1892, 3 parts, pp. 1–328 + 12.
38. " " xxxi, 1893, 3 parts, pp. 1–372 + 12.
39. " " xxxiii, 1894, 2 parts, pp. 1–259.
40. List of surviving members, Jan. 9, 1892.

MUSEO NACIONAL DO RIO DE JANEIRO, RIO DE JANEIRO

CALIFORNIA ACADEMY OF SCIENCES, SAN FRANCISCO

204. Proceedings, second series, vol. 3, pt. 2, pp. 1–390.
205. " " " 4, pt. 1, pp. 1–462.
206. Occasional papers, iv, 1893, pp. 1–412.

GEOLOGICAL SURVEY OF NEWFOUNDLAND, ST. JOHNS

ACADEMY OF SCIENCE, ST. LOUIS

COMMISSAO GEOGRAPHICA E GEOLOGICO, SAO PAULO

UNITED STATES GEOLOGICAL SURVEY, WASHINGTON

41–59. Annual Reports, No. 1, 1880 to No. 13, 1892.
60–82. Monographs I–XXII.
83–144. Bulletins Nos. 1–62.
145. " No. 65.
146–165. " Nos. 67–86.
166–193. " Nos. 90–117.
194–203. Mineral Resources, vols. for 1883–1893.

SMITHSONIAN INSTITUTION, WASHINGTON

207–215. Reports, 1884–1893.

UNITED STATES NATIONAL MUSEUM, WASHINGTON

216. Bulletin No. 30, pp. 1–333.
217. " No. 33, pp. 1–198.
218. " No. 42, pp. xviii + 1–256.
219. " Handbook and catalogue of building and ornamental stones, G. P. Merrill.
220–252. Thirty-three miscellaneous papers.

LIBRARY OF CONGRESS, WASHINGTON

(*b*) *EUROPE*

DEUTSCHE GEOLOGISCHE GESELLSCHAFT, BERLIN

KONIGLICH PREUSSISCHEN GEOLOGISCHEN LANDESANSTALT UND BERGAKADEMIE, BERLIN

299–302. Jahrbuch, Band x, 1889—xiii, 1892.

SOCIETE GEOLOGIQUE SUISSE, BERNE

R. ACCADEMIA DELLE SCIENZE DELL' ISTITUTO DI BOLOGNA, BOLOGNA

401. Memorie, Serie v, Tomo ii, 1891, pp. 1–364, 4to.

SOCIÉTÉ BELGE DE GEOLOGIE DE PALEONTOLOGIE ET D'HYDROLOGIE, BRUSSELS

416–418. Bulletin, Tomes i, 1887—iii, 1889.
419. " " iv, 1890, Fasc. 1, 2.
420. " " v, 1891, Fasc. 1.
421–422. " " vi, 1892—vii, 1893.
423. " " viii, 1894, Fasc. 1.

BIUROULUI GEOLOGICA, BUCHAREST

437. Annarulŭ, 1882–'83, Nos. 1–2 (edition Francaise), pp. 1–180.
438. " 1882–'83, No. 3, pp. 1–7 + 149–316 + 85–116.
439. " 1882–'83, No. 4, pp. 317–460.
440. " 1884, No. 1 (edition Francaise), pp. 1–75 + 84.
441. " 1885, No. 1, pp. 1–339 + 117–158.
442. " 1887, No. 1, pp. 1–53 + 159–190.
443. General geological map of Roumania, 24 sheets.

MAGYARHONI FOLDTANI TARSULAT, BUDAPESTH

357. Földtani Kozlöny, xxii Kötet, 1892, 5–12 Füzet.
358. " " xxiii Kötet, 1893.
359. " " xxiv Kötet, 1894 (except pp. 261–352).

NORGES GEOLOGISKE UNDERSOGELSE, CHRISTIANIA

432. Selbu, 1890, pp. 1–39.
433. Aarbog for 1891, pp. 1–100.
434. Salten og Ranen, 1890, pp. 1–232.

ACADEMIE ROYALE DES SCIENCES ET DES LETTRES DE DANEMARK, COPENHAGEN

428–431. Oversigt i Aaret, 1891–'94.
432. Fortegnelse, I Tidsrummet, 1742–1894, pp. x + 1–135.

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